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SOLID WASTE MILLING AND DISPOSAL ON LAND WITHOUT COVER

VOLUME I. SUMMARY AND MAJOR FINDINGS

City of Madison, Wisconsin

PREPARED FOR
Environmental Protection Agency

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The project began as a practical demonstration to investigate the concept of milling solid waste for landfill disposal without applying daily cover. The project wasintended to gather data on the operation and cost of milling equipment, the use of milled solid waste in a landfill, and the characteristics of milled solid waste --all from a practical standpoint. Eventually, however, project personnel carried out detailed investigative work on both milled and unprocessed solid waste. To determine whether landfilling milled solid waste lived up to the approval given by European landfill operators, it became necessary to design experiments involving rats, flies, leachate, gas, trees, etc. in hopes of quantifying such factors.

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SOLID WASTE MILLING AND DISPOSAL ON LAND WITHOUT COVER

Volume I: Summary and Major Findings

This final report (SW-62d.1) on work performed
under Federal solid waste management demonstration grant No. G06-EC-00004
to the City of Madison, Wisconsin, was written
by JOHN J. REINHARDT *and* ROBERT K. HAM
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U.S. ENVIRONMENTAL PROTECTION AGENCY
1974

This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of commercial products constitute endorsement or recommendation for use by the U.S. Government. The position taken by the U.S. Environmental Protection Agency on the disposal of uncovered, unmilled solid waste is published as Appendix B.

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INTRODUCTION

This report covers the highlights of almost seven years of work at Madison, Wisconsin, carried on under a demonstration grant from the Department of Health, Education and Welfare and the Environmental Protection Agency. This report is one of two volumes. Volume I is a summary of the major findings and is intended for those who wish to gain general information on the project. Volume II contains condensations of data gathered during the project and has been arranged in sub-reports intended for the researcher who may wish to review the data. **Volume II will also be made available through the National Technical Information Service (NTIS), Washington, D.C.**

The project began as a practical demonstration to investigate the concept of milling refuse for landfill disposal without daily cover in what is hereafter referred to as a millfill. The project was intended to gather data on the operation and cost of milling equipment, the use of milled refuse in landfill, and the characteristics of milled refuse - all from a practical standpoint. Project personnel ended up doing detailed investigation work, on both milled and unprocessed refuse, which was far removed from the idea of a demonstration project. In order to show that landfilling milled solid waste without daily cover lives up to the praise offered by European landfill operators, it was necessary to design experiments involving rats, flies, leachate, gas, trees, etc., which hopefully would quantify such factors. While some crude techniques for making measurements on these parameters existed in the solid waste field, only a few suggestions could be gleaned from the literature or from similar projects. It was therefore necessary to pioneer in such areas as to how to measure particle sizes of the milled product and how to compare the occurrence of flies on a sanitary landfill face and the surrounding area with their occurrence on a millfill.

The project investigators used not only the numerical evaluations but also seven years of field experience and observations in drawing the conclusions presented in this report. It should also be kept in mind that there is a difference between the idealized, environmental aspects of a covered unprocessed landfill and what occurred in the field during years of evaluation. Thus, comparisons betweeen milled and unprocessed refuse were based on actual day-to-day field evaluations and not on theoretical considerations.

It was interesting to note, during a tour in 1970 of European milling facilities by the principal investigators in this project, that the Europeans involved in solid waste management have evolved into incineration schools, composting schools, landfilling schools, etc. They seem to be even more opinionated in their approach to processing and disposal than their American counterparts. But among American solid waste experts there is also appearing a "school" mentality involving such processes as baling, sanitary landfilling, milling, composting and incineration. In reading this report one should keep an open mind as to where milling of solid waste really fits into the scheme of solid waste management. Solid waste management operations include storage, collection, transportation, processing and disposal. Milling is a method of processing, not the method of processing or a method of disposal. The important thing to consider is not, "What is wrong with milling?" but "Does milling fit into a particular community's or private operator's solid waste management system?" Unfortunately, a controversy rages about milling and running millfill sites. As in such controversies, one side is likely to present milling as a magical solution to all solid waste disposal problems and the other to present it as an expensive, unreliable, impractical approach to a small portion of the problem. The true value of milling, of course, lies somewhere in the middle.

There have been many changes in solid waste management since this project was conceived in 1966. Regulations in the areas of air pollution, water pollution and land disposal of waste have had their impact on the field. Emphasis in disposal has greatly shifted from the public health and economic aspects of the problem to the esthetic aspects. With this change in philosophy, the traditional engineering economics approach to the solid waste disposal has been altered somewhat. In the past, a method was chosen for a disposal facility design based on the acceptable health standards with little regard to how the process affected the sensibilities of the general public. Screening of disposal sites, odor abatement control, improved architectural design of buildings, etc. were usually not included in the design because they did not turn out to be the most economical solutions. It has now become necessary to evaluate the esthetic solution to the disposal problems as well. It is hoped that the following report will shed some light on how milling can fit into a locality's solid waste management system from the standpoint of economics, health,safety, and esthetics.

While the project did not provide black and white answers to all the questions, it certainly illuminated some of the dusty dark areas in solid waste management and demonstrated that milling can be a valuable aid for land disposal, incineration, and some of the future schemes for resource recovery.

ACKNOWLEDGMENTS

The persons who initiated the refuse reduction project in Madison included Arnold Meyer, Vice President of the Heil Company; Gerard Rohlich, Professor of Civil Engineering, University of Wisconsin-Madison; Edwin Duszynski, Director of Public Works, City of Madison; John Thompson, former City Engineer, City of Madison; and James Brophy, Superintendent of Streets, City of Madison.

Overall responsibility for the project has been in the hands of John J. Reinhardt, Principal Civil Engineer, City of Madison. Robert K. Ham, Associate Professor of Civil and Environmental Engineering, University of Wisconsin-Madison, was in charge of the University efforts in the project. Evaluations were carried out under direct supervision of Warren K. Porter and Gerald W. Sevick, Project Specialists.

Major investigations were conducted by Charles R. Anderson, Larry Hendrickson, James R. Boyle, Rameschandra Gawalpanchi, Everett W. Clodfelter, Fred Courtsal, Gier Widgel, Vincent Geier, and Walter L. Gojmerac.

Assisting in the project have been Gary Coley, Robert Karnauskas, Kenneth Brunner, Herbert Hanneman, David Potwin, Richard Presney, Ellsworth Fisher, Earl Ulsrud, Charles Maas, Raymond Dillabough, Warren Kimberley, Richard Steinhofer, William Martin, Mary Smits, Eugene Davenport, and Al Kelly.

Student assistants have included Wendy Arndt, Douglas Lindquist, John Rogalski, William Merry, Robert Schmiedlin, and Daniel W. Benjamin.

Production of the final report for this project has been the responsibility of John Wolf and Austin Henry.

Special recognition is given to Doris Habich for typing and retyping the project's numerous reports over the past six years.

This demonstration project has been supported by the U.S. Enviromental Protection Agency in cooperation with the City of Madison, Wisconsin. Two of their project officers, David Arella and Roger D. Graham, have provided valuable assistance.

DEFINITIONS

Several terms used throughout this volume require short definitions. Most of the definitions are adapted from APWA Municipal Refuse Disposal, Chicago, (1970), and the EPA Publication Solid Waste Management Glossary (SW-108ts), 1972.

1) Refuse (also called solid waste). Useless, unwanted, or discarded material. This report is concerned primarily with residential (also called domestic) and light commercial refuse -- that is, all solid waste that normally originates in a residential environment. Industrial, institutional, and large quantities of commercial refuse are generally collected by private firms in Madison and are not normally milled. Large tree cuttings, bulky items, and construction-demolition debris are also handled separately at Madison.

2) Garbage (also called food waste). Animal and vegetable waste resulting from handling, storage, sale, preparation, cooking, and serving of foods.

3) Rubbish. A general term for solid waste -- excluding garbage and ashes -- taken from residences, commercial establishments, and institutions.

4) Milled Refuse. Refuse that has been mechanically ground, shredded or pulverized.

5) Unprocessed Refuse. To avoid confusion, this term will be applied uniformly to unmilled, crude, or raw refuse.

6) Cell. A volume of compacted solid waste which may be enclosed by natural soil or cover material in a sanitary landfill, not covered as in the case of test volumes of milled refuse, or enclosed in concrete beds in other test situations.

7) Sanitary Landfill. A method of disposing of solid waste on land by utilizing sound engineering and planning principles, by spreading the waste in layers, compacting it to the least practical volume, and covering it with soil at the end of each working day.

8) Bulky Items. Madison routinely collects large, bulky items such as furniture, tires and mattresses separately. Such material is not milled but landfilled separately.

9) Rejects. These are items which the mills ballistically separate because they cannot be pulverized to the desired particle size.

10) Cover. Soil which is placed over material in a sanitary landfill at specified intervals, usually daily.

11) Vector. An organism that is capable of transmitting a pathogen.

12) Leachate. Liquid that has percolated through solid waste and has extracted, suspended, or dissolved material from it.

13) Actual Refuse Density. The figure derived by dividing the weight of a portion of refuse by the volume of that refuse.

14) Effective Refuse Density. The figure derived by dividing the weight of a load of refuse by the volume of landfill space it takes up (including any cover).

15) Operational Production Rate. Tons processed during the time in which a mill is actually running. Down time is omitted from this figure; thus, it is a measure of a mill's efficiency.

16) Down Time. In evaluations of the mills separately, time when a mill was shut down due to mechanical problems. In evaluations of the two-mill operation, all times during which the mills were not grinding refuse, between the initial start-up of the mill to the shut down at completion of the production day (e.g., any time the mill is not running during normal working hours).

17) Overall Production Rate. Tons of refuse processed divided by time during which the mill was grinding, plus down time. Thus, it is a measure of the plant's efficiency.

18) Millfilling. An engineering method of disposing of solid waste on land without daily cover by milling the waste, spreading it in layers and compacting it to the smallest volume practical.

DEVELOPMENT OF MILLING IN EUROPE

Milling was begun in Europe to provide material suitable for composting. The original single- or double-rotor hammer mills were designed to handle homogeneous materials; thus ungrindable items had to be manually sorted and removed.

A French manufacturer of grain-grinding machines made the crucial observations that led to the capability of milling heterogeneous material such as refuse. He was trying to learn why his grain mill was unable to grind high-moisture corn, and during an investigation of this problem he had a portion of the cover on the machine cut out. He observed that dry grain particles were readily ground. The softer, spongier, moister grains, however, remained unground and were accelerated through the opening in the top of the machine. The manufacturer of grain grinders thus learned that nongrindable objects can be ballistically separated from grindable objects in a mill. The ballistic rejection feature of the mill was awarded U.S. patent 3,082,963 on 26 March 1963.

The idea of ballistically separating nonmillable refuse through a "chimney" above a hammermill was developed into a test machine which was installed in Meaux, France in the early 1950's. Since there was no composting plant in the vicinity, the milled refuse was simply deposited on land near the machine. Amazingly, the milled refuse did not create a nuisance.

The original mill at Meaux was fed by hand at the inlet opening. It soon became apparent that a mechanical feeding machine would be needed to maximize the machine's output. Development of mechanical feeding machinery took another two years, however.

By 1970 there were over 50 installations employing this type of feeding and milling equipment in Western Europe (Figure 1). Almost all landfilled the milled refuse without daily cover.

By the mid-1960's, the first Gondard plant was in operation in North America -- at Montreal, Canada. In this plant, two Gondard mills are used in a parallel arrangement for refuse milling by a commercial salvaging company. About 25 percent of the refuse brought to the mill during its first years of operation was salvaged and sold. The major item salvaged was paper. The remainder of the milled refuse was dumped along with unprocessed refuse in an uncontrolled fashion; thus it was difficult to draw conclusions about many aspects of landfilling milled refuse from the Montreal operation.

European experience, however, has indicated that handling milled refuse at a landfill site is simple and convenient. It is merely dumped and graded as desired. Since milled refuse is relatively uniform in size and composition, compaction and settlement are even. The material was reported to provide excellent support for rubber-tired vehicles, and since glass objects are reduced to tiny pieces, damage to tires of landfill machinery is greatly reduced. The nuisance caused by blowing paper and dust produced by packing machinery is greatly reduced. The danger of fire in the landfill is greatly lessened. Many vectors, especially rats and flies, are reduced in number or eliminated from the landfill. Milled refuse is esthetically more pleasing than unprocessed refuse and therefore is more readily accepted by the public. Finally, according to European claims, milled refuse that has been landfilled does not require daily covering.

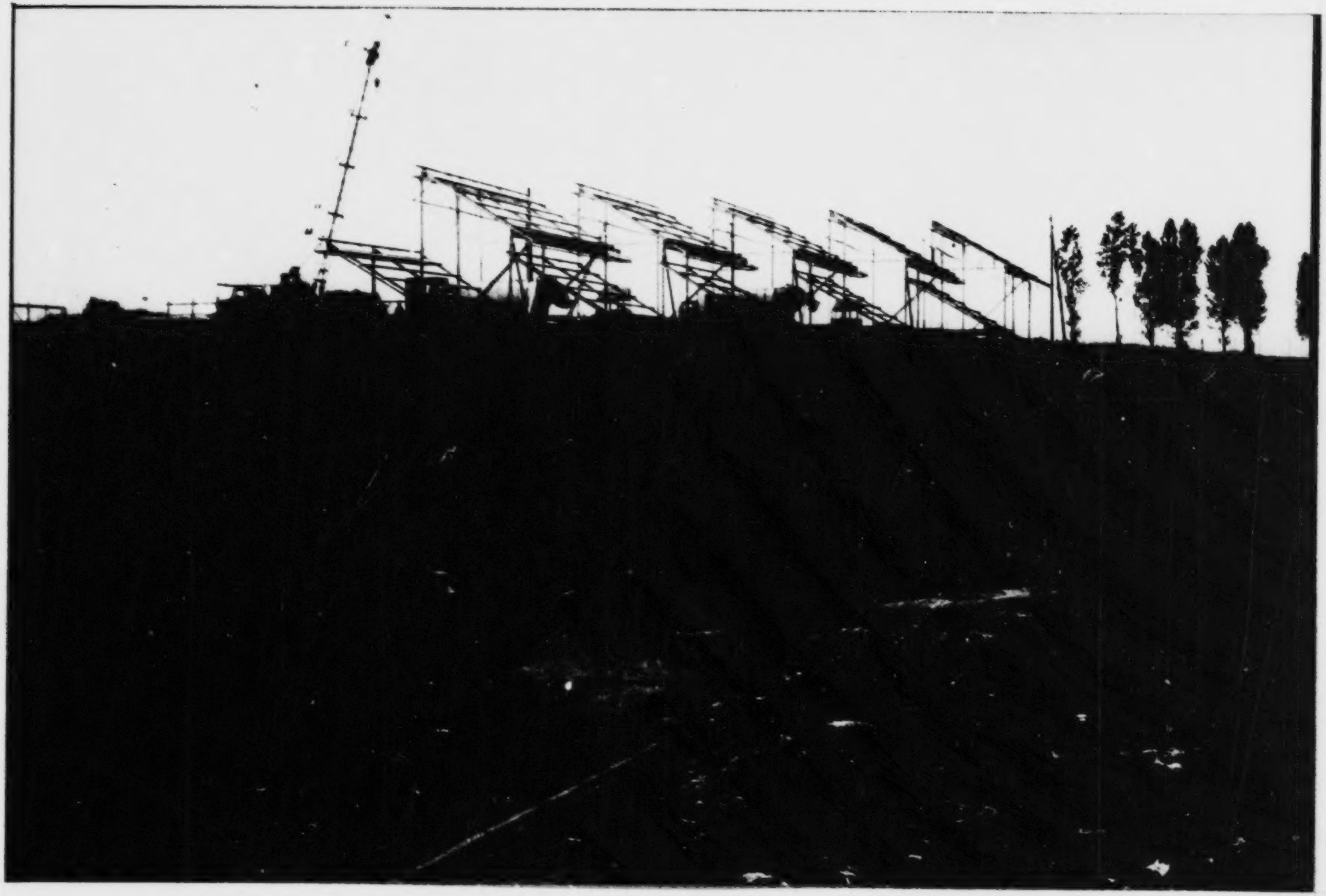


Figure 1. Installation of four Gondard mills at Weisbaden, Germany, 1966.

MADISON'S MILLED REFUSE OPERATION

Historical

The Heil Company of Milwaukee, Wisconsin, manufacturers and marketers of truck bodies for solid waste collection, learned of the Gondard milling process through sales activities in France, Switzerland, Netherlands, and Germany. Company representatives were impressed by the European claims of the attractive features of milled refuse and thus set out to find a city in the United States to undertake a test project involving refuse milling.

An incentive to potential users of the new milling system was the Soild Wastes Act of 1965 which provided matching funds for projects which would demonstrate on a production scale new methods of managing solid waste. Efforts to interest a community in Milwaukee County in trying the new system proved unsuccessful when it appeared that the project would interfere with development of a county-wide incineration system.

Continuing their search, the Heil representatives contacted Professor Gerard Rohlich of the University of Wisconsin-Madison College of Engineering. Professor Rohlich felt that the system warranted investigation and encouraged Madison's Director of Public Works, City Engineer, and Superintendent of Streets and Sanitation to investigate the possibilities and to view the Montreal operation.

An inspection trip to the Montreal facility took place in February 1966, following a prolonged thaw. The haul roads into the landfill site were almost impassable to automobiles. However, the traffic-bearing quality of the uncovered milled refuse in the landfill was remarkable. The visitors were able to walk on the refuse surface without overshoes, and loaded trucks sank only three or four inches into the material.

The ease of operation at the Montreal landfill, even under adverse conditions, convinced the Madison officials to recommend to the Madison Common Council that they be permitted to apply for a grant to fund a demonstration project. The proposed project would investigate European claims that milled refuse can be landfilled without daily cover as well as determine what modifications would be necessary to adapt the system to refuse generated in this country. The cost of such a system would also be carefully documented, and the characteristics of milled refuse would be studied.

In April 1966, the Common Council approved the submittal of a proposal to the Department of Health, Education and Welfare and designated the Olin Avenue landfill site as the location of a proposed plant.

The City of Madison received a three-and-one-half-year grant, number 5-DOI-UI-00004, from HEW in June 1966. The grant was renewed and expanded several times to cover additional work. Participants in the demonstration project included:

1) The City of Madison, which provided the plant site, site improvements, operating personnel, partial matching funds, and, of course, the refuse.

2) The Heil Company, which furnished, installed, and modified the equipment and provided partial matching funds for the original equipment and for some phases of the evaluation. Under terms of a purchase option contract, Madison bought the equipment in 1969 after it proved successful.

3) The University of Wisconsin-Madison, which collected data and evaluated the project.

Original Plant

The Olin Avenue site for the Madison Refuse Reduction Plant is a 60-acre marshy area which had been operated as an open-burning dump from 1942 to 1960. It was operated as a landfill after that time. Cells for evaluation of the milled refuse project had to be constructed above ground using the so-called area method because the entire Olin Avenue site had been levelled with one ten-foot lift of covered refuse prior to the milling project. The water table ranges from 3 to 10 feet below the surface, depending on the season and location in the landfill.

A minimum floor area for the plant was considered necessary because of poor subsoil conditions at the site. Soil borings indicated the need for surcharging the site to compress deep-lying organic silt. This process delayed the placement of foundations until December 1966. The building was completed a few months later. The original plant was a 64x104 ft. enameled steel panel building with a concrete floor for refuse storage. A scale was also installed for weighing incoming packer trucks (Figure 2).

The Gondard machinery was delivered completely dismantled, but despite unfamiliar plans for its assembly, the mill was erected and the plant wired in only two months. The mill was operated for the first time on 14 June 1967 and shakedown runs were made throughout the summer.

Madison began using the mill in September 1967. At the same time, the city instituted weekly collection of combined refuse on the west side of town to replace separate collections of garbage and rubbish. Such combined collection was in accord with Madison's long-term desires and was in line with the needs of the demonstration project.

Description of Gondard Equipment

The Gondard hammermill installed at the Olin Avenue site in 1967 was equipped with forty-eight 1-3/16x4x11 in. swinging hammers on four shafts. The 15-lb. hammers are driven at 1150 rpm by a 150 hp motor (Figure 3). The patented chimney was included to permit ballistic rejection of large, unmillable objects. Ballistic rejection occurs when such objects are struck by the hammers sufficiently hard that they pass the 27-foot length of the chute, strike a deflection plate, and come down a separate chute. This feature allows ungrindable objects to bypass the grates through which milled material leaves the mill (Figure 4).

As noted, the reduction plant was designed to minimize floor space This design led to complex system of three feeding conveyors (Figure 5). The motors for the three conveyors are controlled by a special unit that allows the operator to vary the speed of the two rubber-belt conveyors or the conveyor in the 75-cu. yd. feed bin. The mill also includes a system to stop all three conveyors when power input to the mill motor exceeds 125 percent of rated load for 5 consecutive seconds.

The original discharge conveyor was a 3-foot-wide rubber belted conveyor suspended from a trolley which permitted it to swing from one to the other of two 10-cu. yd. portable load lugger bins.

The Gondard mill and conveyors were imported from France on the basis of satisfactory performance in Europe. Almost immediately, however, it became apparent that refuse generated in Madison was different from European refuse. For example, Madison's refuse contains more large items such as boxes. These differences, as well as mechanical problems, required

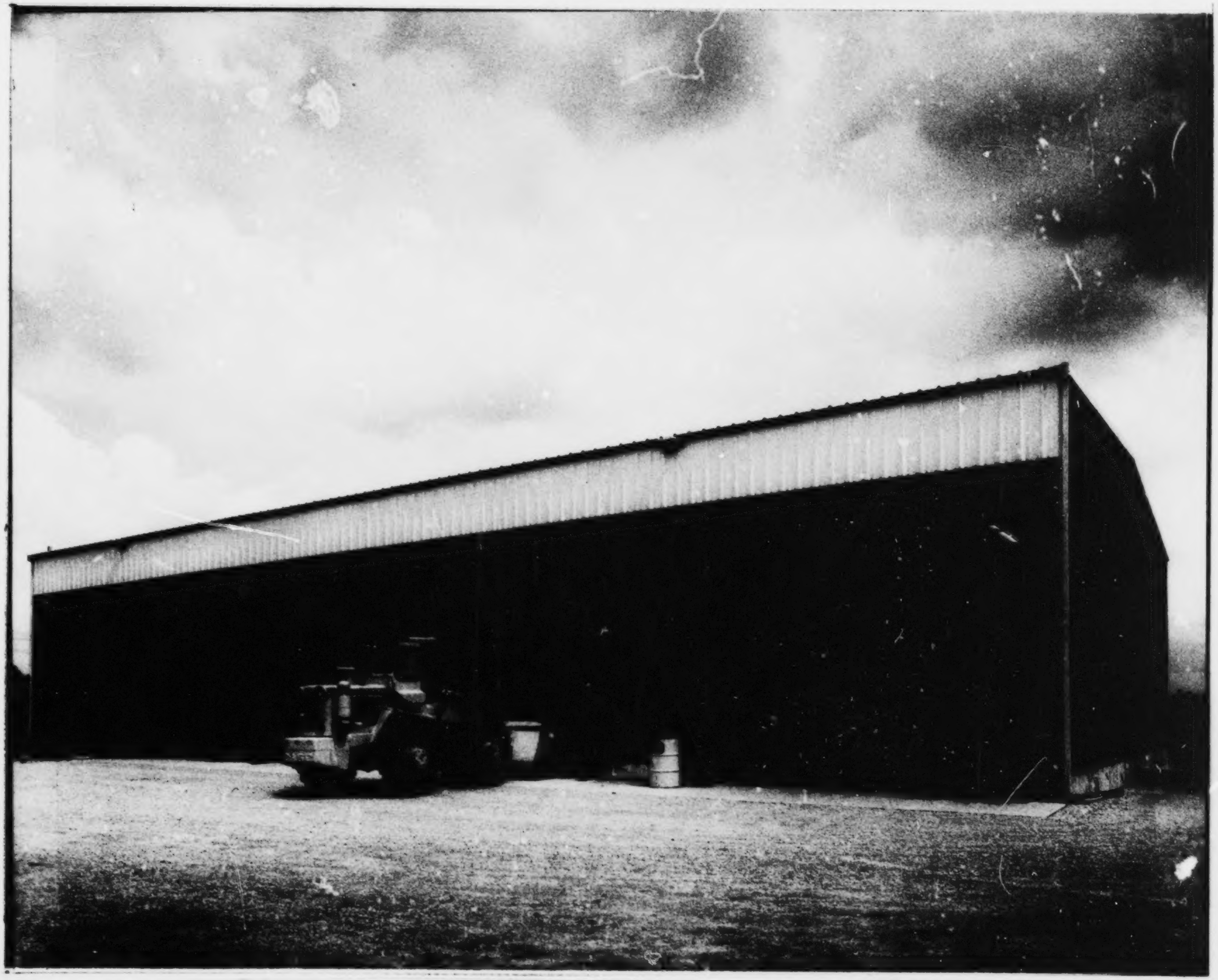


Figure 2. Refuse Reduction Plant at Madison, Wisconsin, 1967.

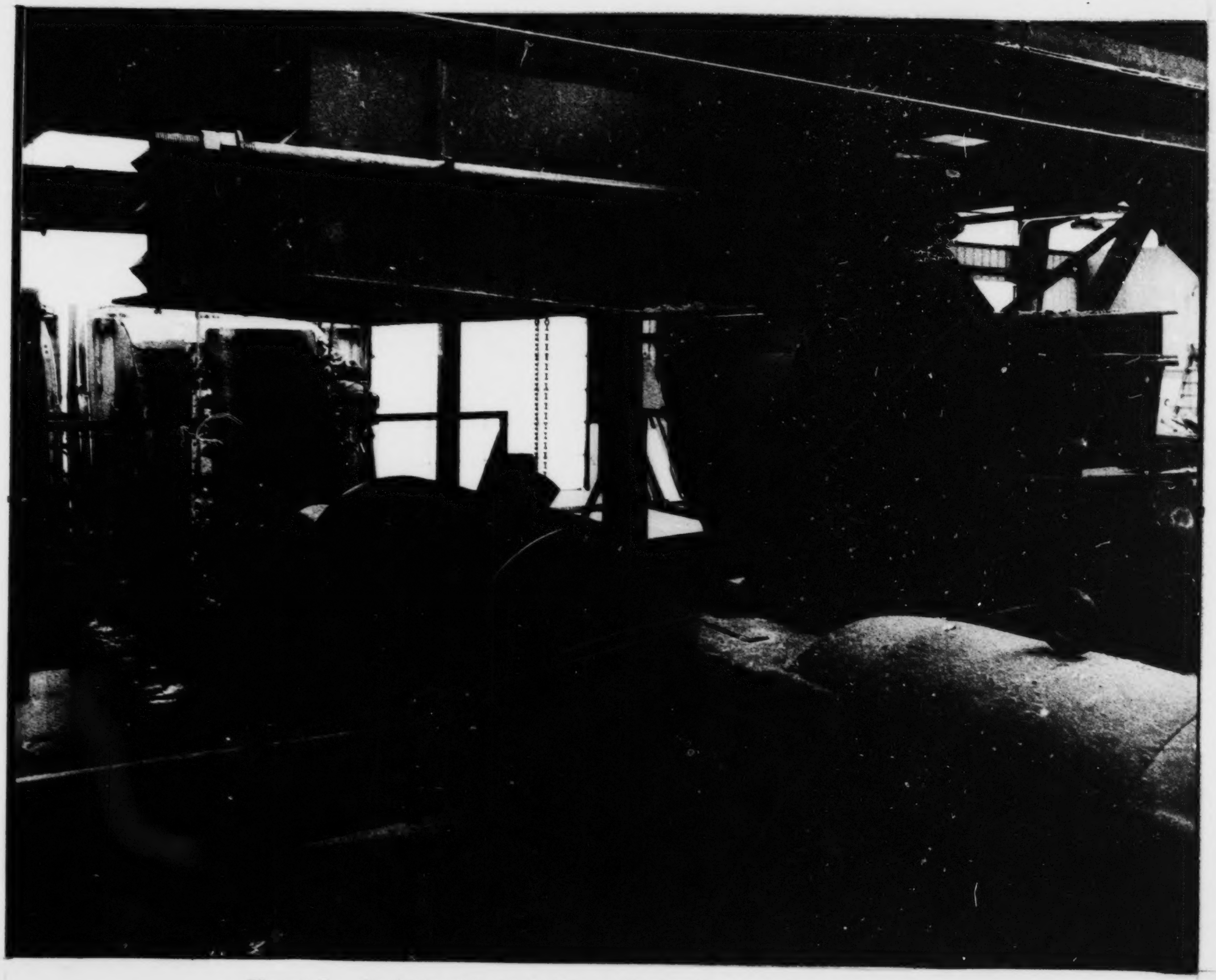


Figure 3. Gondard mill at Madison, Wisconsin. Housing opened to show horizontal rotor and hammers.

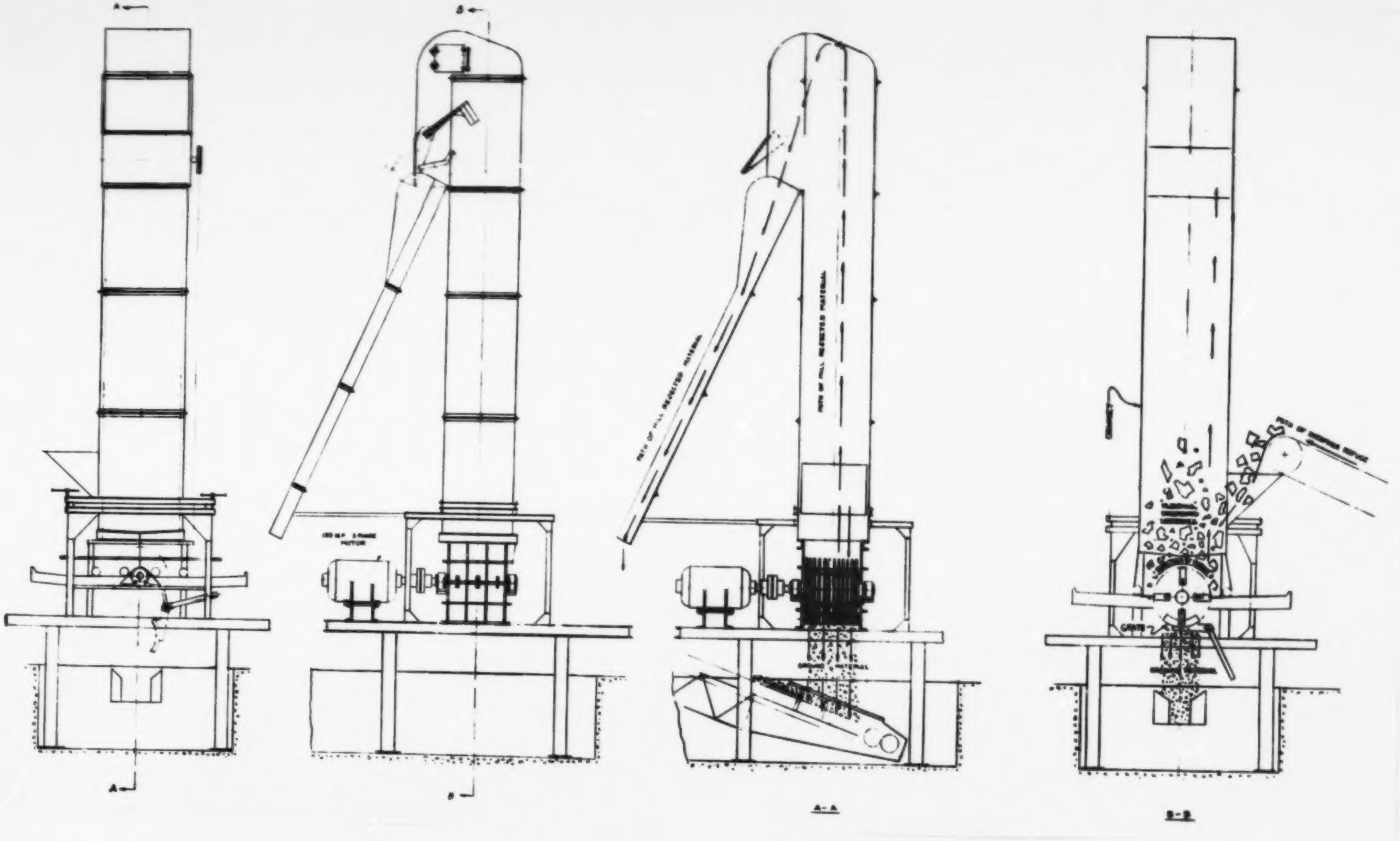
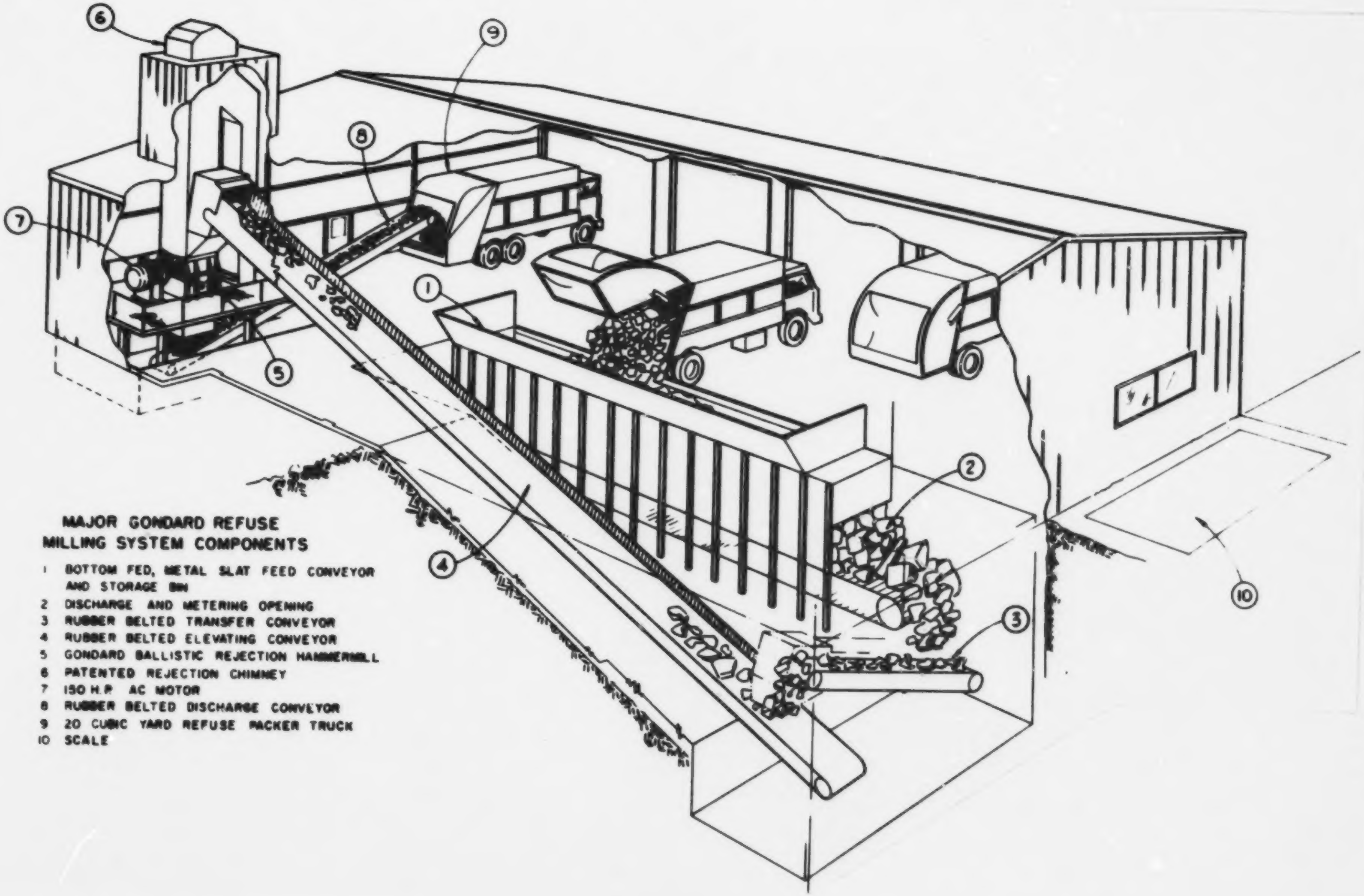

A
B
100 H.P. 3 PHASE MOTOR
PATH OF MILL REJECTED MATERIAL
GRATE
PATH OF INCOMING REFUSE
A-A
B-B

Figure 4. Side view of the Gondard mill and rejection tower.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MAJOR GONDARD REFUSE
MILLING SYSTEM COMPONENTS
1 BOTTOM FED, METAL SLAT FEED CONVEYOR AND STORAGE BIN
2 DISCHARGE AND METERING OPENING
3 RUBBER BELTED TRANSFER CONVEYOR
4 RUBBER BELTED ELEVATING CONVEYOR
5 GONDARD BALLISTIC REJECTION HAMMERMILL
6 PATENTED REJECTION CHIMNEY
7 150 H.P. AC MOTOR
8 RUBBER BELTED DISCHARGE CONVEYOR
9 20 CUBIC YARD REFUSE PACKER TRUCK
10 SCALE

Figure 5. Original layout of Madison's Refuse Reduction Plant; packer truck being loaded for trip to landfill.

modification of the Gondard system after installation at Madison. Some of these modifications included:

1) Addition of 6-in. cleats to supplement the 3-in. cleats in the feed bin conveyor for handling the large items in Madison's refuse.

2) Installation of spray bars around the area where refuse leaves the bin conveyor and at the entrance to the mill to help reduce dust problems.

3) Redesign of several components of the feed mechanism to prevent jams and improve uniformity of feeding.

4) Revision of the servo motor on the bin feeder to allow the operator to change conveyor speeds rapidly.

These modifications and other improvements in plant operation reduced down time due to conveyor and mill jams to well below the 13 minute per day average recorded between 1 April and 29 November 1968 with the original equipment.

Operational Aspects of the Gondard System

In the Gondard system, incoming refuse is first weighed and then emptied in the 75-cu. yd. storage bin or on the floor when the feed bin is full (Figure 6). A front-end loader is used to push refuse from the floor into the bin. The combination of refuse storage in a bin and on the floor was chosen to eliminate the need for an overhead crane and operator, to minimize handling of the refuse, and to make it easier to clean up the dumping area after each day's operation.

At the bottom of the storage bin is a conveyor with metal cleats that move refuse out one end of the bin and onto a rubber belt at right angles to the bin conveyor. This second conveyor, in turn, dumps the refuse onto a third belt, again at right angles to the second conveyor. This rubber-belt conveyor lifts the refuse and drops it into the hammermill through the side of the chimney. A variable speed drive allows the flow of refuse to be controlled by increasing or decreasing the speed of the conveyors.

In the mill, the refuse is either pulverized to sizes small enough to pass through a grate or rejected through the chimney.

The original method for transporting the refuse from the mill to the landfill was a Load Lugger detachable container system consisting of a flatbed truck with hydraulic arms to lift a 10-cu. yd. bin onto the bed. Three bins were provided initially. One bin was placed under the reject chute and could hold the items rejected during one or two days of milling. The other two containers were located at the end of the conveyor bringing milled refuse from the mill. The conveyor was mounted on a track so that it could be switched from one container to the other. When one container was filled, a man stationed at the truck levelled the load, switched the conveyor to the other container, took the full load to the landfill, and finally replaced the empty container in its original location. By the time he returned, the second container was usually almost full. This man was thus continually occupied in emptying containers. Because of the fluffy nature of the freshly milled material, these 10-cu. yd. containers held only 2,500 to 3,000 lbs.

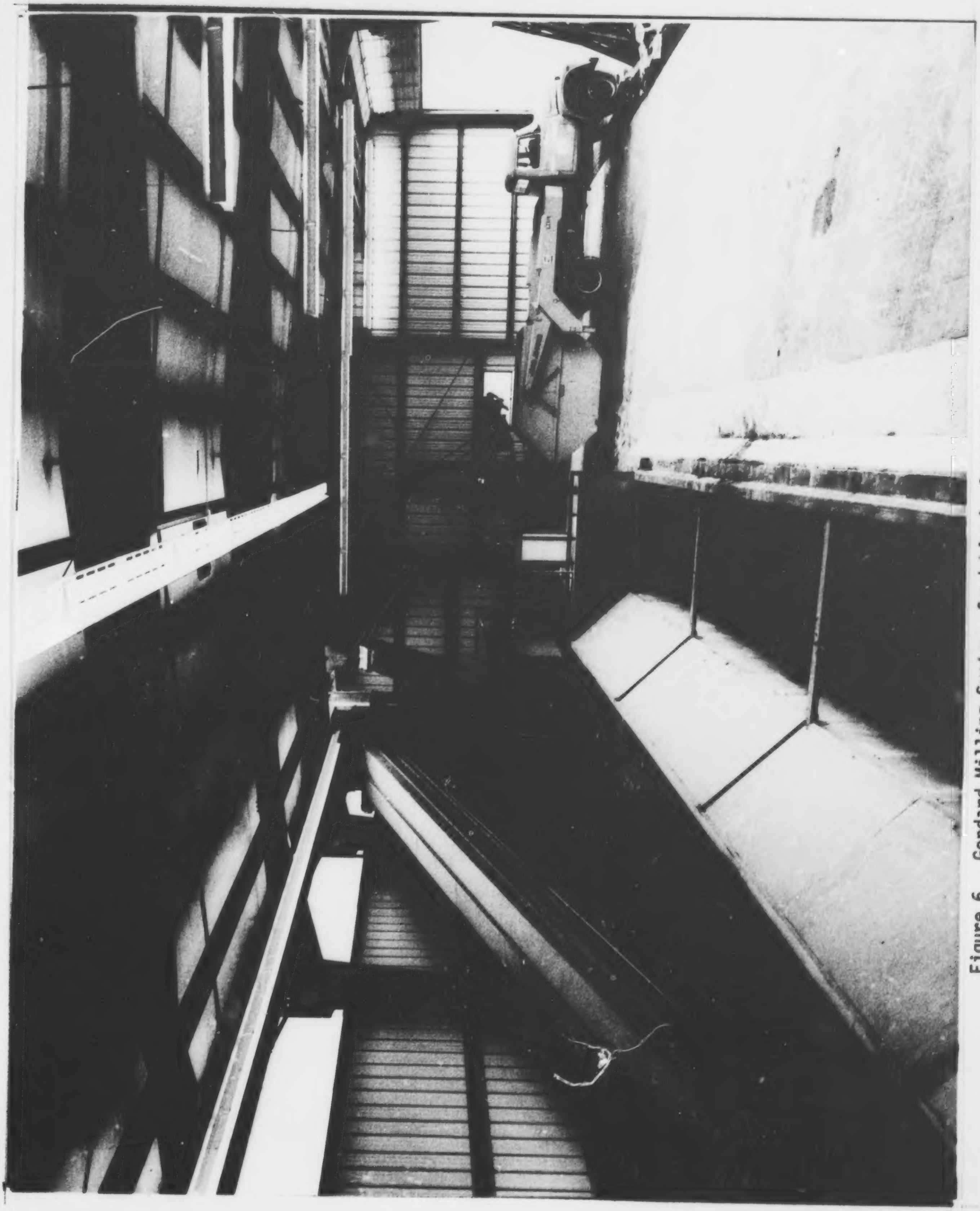


Figure 6. Gondard Milling System; feed bin in foreground and haul-away load lugger in background.

A change to conventional refuse packer trucks to transport milled refuse was made in January 1968, when two old packers were pressed into emergency service. Since the trucks needed frequent repair and since a person was needed to actuate the packing mechanism every few minutes, these trucks were retired in November 1968.

Also during 1968, two models of 20-cu. yd. packers were tested. Neither was able to keep pace with the volume of refuse discharged from the mill.

The final collection and transportation system used during the tests involved two prototypes of a 25-cu. yd. packer truck planned for production by the Heil Company. These trucks had a packing mechanism that could be continuously cycled by mechanical means. This system reduced both manpower needs and the number of trips to the landfill.

Gondard Production Rates

During the year of experimental trials with the Gondard system, the grate at the bottom of the mill, through which milled refuse passes, was changed systematically to determine optimum grate size. Grate size is the space between bars of the grate. Considerations in optimization included machine capacity, operating costs, landfill space required, and particle size. Initially, plans called for using 2-, 3 1/2-, 4-, 5-, and 6 1/4-in. grates; however, tests with the 2-in. grate were discontinued almost immediately because it yielded particles finer than required for landfill operating and was slowing production.

Tables 1 and 2 show production rates at various seasons and with different grate sizes. Two production rates were calculated: one based on machine milling time alone and the other based on machine milling time plus down time. Thus, "operating" production rate is the tonnage processed during the time the machine is actually milling, while "overall" production rate is the tonnage processed during mill milling time plus down time. Not included in the overall rate is time lost because the plant was out of refuse or because of the time lapse from arrival of the first load to the start of milling operations. These factors were not included because they do not reflect machinery limitations in the plant itself. Time lost because of these nonmachine problems will be taken into account and discussed further in the section on costs.

The optimum grate size for use in Madison was found to be 5-in. This yields the highest "operating" production -- 9 tons per hour- -- at lowest cost without producing blowing paper problems in the landfill. The "operating" production rates for the 3 1/2- and 6 1/4-in. grates were 8.6 and 9.4 tons per hour, respectively, during the tests.

Items rejected from the mill were collected and weighed from September 1967 through January 1968. During this time it was found that between 1 and 7 percent, by weight, of the total refuse was ballistically separated when the reject chute extended 27 feet vertically above the mill.

TABLE 1

GONDARD OVERALL PRODUCTION RATE VS. GRATE SIZE - TONS PER HOUR
(Operating Plus Down Time)

Period	Grate Size (opening between bars)		
	3 1/2 Inches	5 Inches	6 1/4 Inches
Fall 1967	6.0	-	8.4
Winter 1967-68	6.8	-	7.0
Spring 1968	6.9	7.8	7.9
Summer 1968	7.7*	8.0	8.1
Fall 1968	-	7.6	-
Winter 1968-69	8.1*	-	-
Spring 1969	9.2*	-	-
Average - last full year	8.3	7.4	7.7
Projected Average - based on improvements in support equipment	8.4	9.0	9.4

* The opening between the bars was actually four inches.

TABLE 2

GONDARD OPERATING PRODUCTION RATE VS. GRATE SIZE - TONS PER HOUR
(Operating Time Only)

Period	Grate Size (opening between bars)		
	3 1/2 Inches	5 Inches	6 1/4 Inches
Fall 1967	6.8	-	9.3
Winter 1967-68	7.0	-	7.3
Spring 1968	7.1	8.2	8.1
Summer 1968	8.0*	8.2	8.4
Fall 1968	-	7.9	-
Winter 1968-69	8.4*	7.2	-
Spring 1969	9.7*	-	-
Average - last full year	8.7	7.7	8.1
Projected Average - based on improvements in support equipment	8.8	9.3	9.7

*The opening between the bars was actually four inches.

Plant Expansion

The original Gondard project was largely an effort to gain experience. By late 1968 it appeared that milling refuse did offer enough advantages for **Madison** to warrant enlargement of the project. Also at this time the Heil Company became interested in evaluating the English-manufactured Tollemache hammermill. In addition, the City of Madison was interested in revising the existing facility, in cooperation with the Heil Company, utilizing the experience gained during the Gondard tests. Under a two-year renewal grant (2-G06-EC-00004-04A1) from HEW, Madison, The University of Wisconsin-Madison, and the Heil Company expanded their objectives to include:

1) Installation and evaluation of the Tollemache mill;
2) Installation and evaluation of a new feed system;
3) Installation and evaluation of a stationary packer with 75-cu. yd., self-unloading transfer trailers;
4) Expansion of the refuse reduction plant to permit operating two shifts;
5) Evaluation of operating the Gondard and Tollemache mills simultaneously for two shifts.

Late in 1970 and early in 1971, a 6,500 sq. ft. addition was made to the original milling plant to accommodate the expanded objectives of the project (Figure 7). Of this addition, 600 square feet were devoted to shops, offices, control room, and meeting room. Another 1,500 square feet were assigned to testing various components of an air-classification, wood-fiber recovery process being developed by the United States Department of Agriculture Forest Products Laboratory at Madison. The remaining 4,300 square feet were devoted to floor storage of incoming refuse and for maneuvering space for the packer trucks. This increased floor space allows storage of 310 tons of unprocessed refuse versus 85 tons for the original building. Cost of the expansion of the facilities was $98,000, with another $32,000 going toward the research area for experimentation in paper recovery.

The new control room, located on the second floor, is the heart of the plant operation. It contains all systems controls and gives the operator a clear view of the dump floor, both mills, their respective feed systems, and the first section of the takeaway conveyor system. A closed circuit television set-up allows the operator to see the remainder of the takeaway conveyor as well as the stationary compactor. Below the control room is the scale room which was not modified during expansion.

With completion of the expansion, a new, larger front-end loader was purchased to handle the increased volume of unprocessed refuse. Also, a Tennant floor sweeper was bought to reduce man hours devoted to cleanup.

Tollemache System

The Tollemache mill installed at the Madison milling plant in 1969 is a vertical-shaft, ballistic-rejection hammermill (Figure 8). In contrast, the Gondard mill has a horizontal main shaft. The Tollemache mill has funnel shaped outside walls and a rotor which has the shape of a conical surface when spinning. The rotor is driven at 1350 rpm by a 200 hp squirrel cage motor powered by a 3-phase, 440-v source.

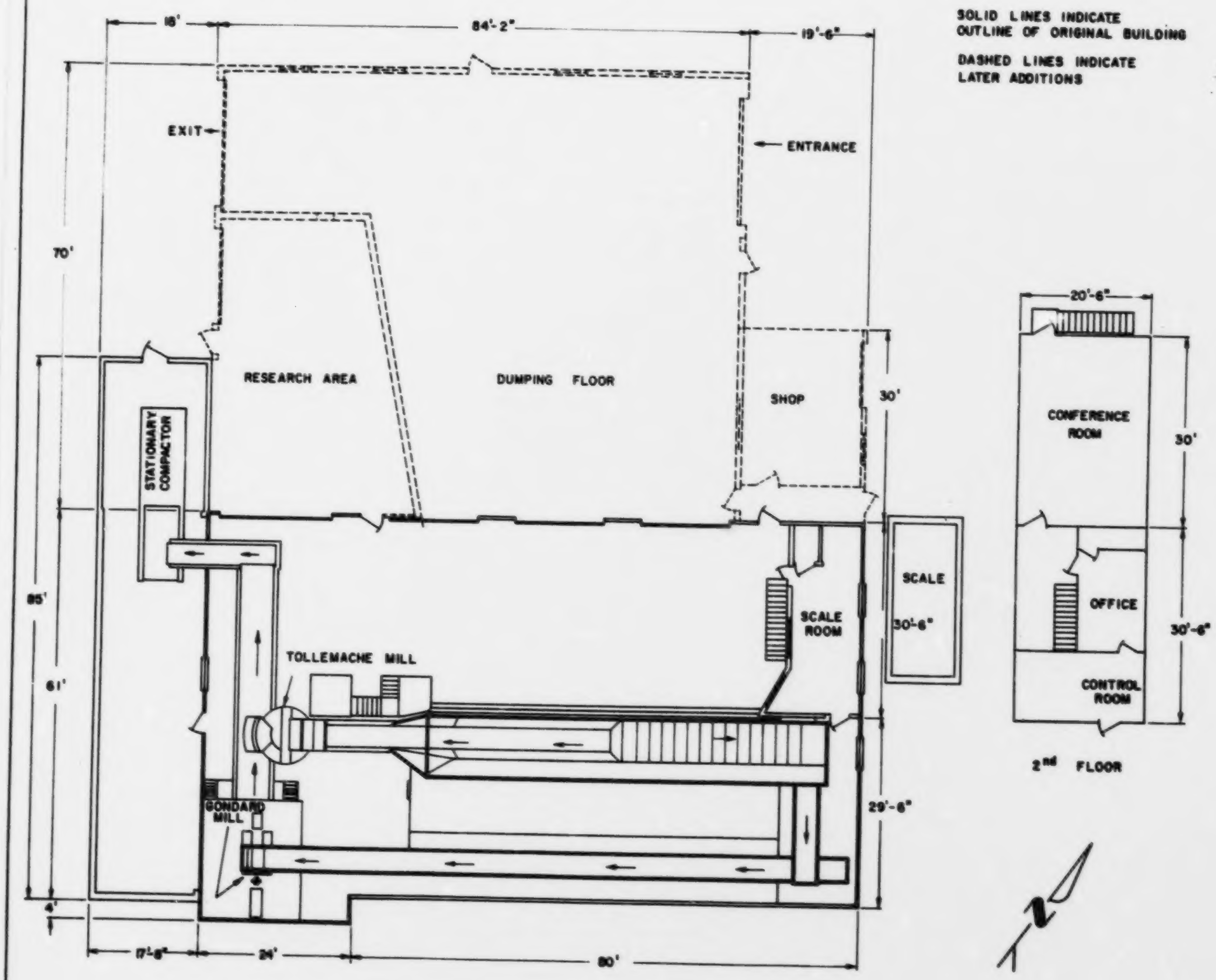

SOLID LINES INDICATE OUTLINE OF ORIGINAL BUILDING
DASHED LINES INDICATE LATER ADDITIONS
16'
84'-2"
19'-6"
EXIT
ENTRANCE
70'
RESEARCH AREA
DUMPING FLOOR
SHOP
30'
STATIONARY COMPACTOR
SCALE
30'-6"
SCALE ROOM
85'
61'
TOLLEMACHE MILL
GONDARD MILL
29'-6"
4'
17'-6"
24'
80'
20'-6"
CONFERENCE ROOM
30'
OFFICE
30'-6"
CONTROL ROOM
2nd FLOOR
N

Figure 7. Floor plan of the Madison Refuse Reduction Plant after completion of expansion in 1971.

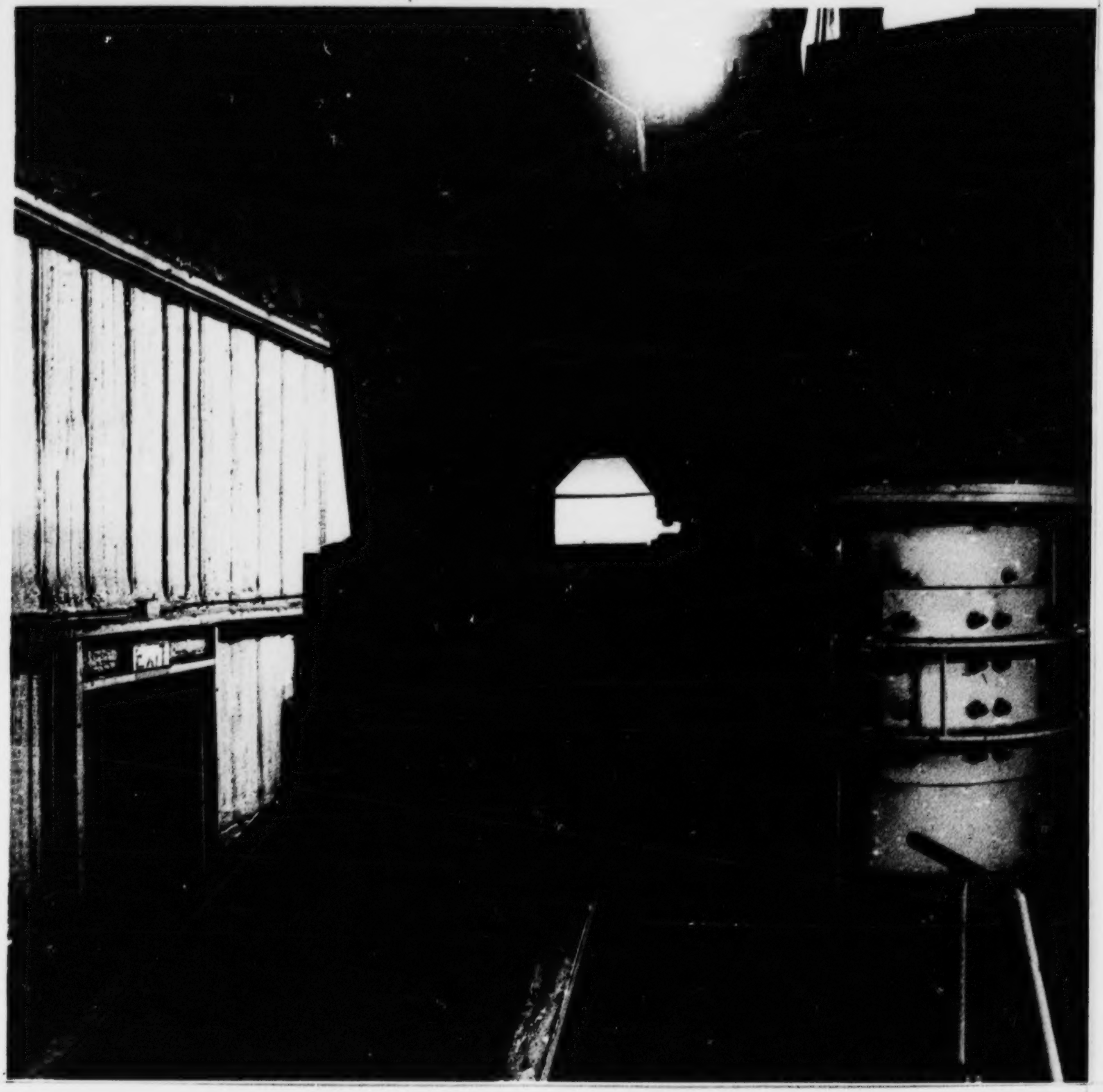


Figure 8. Vertical-shaft Tollemache mill at Madison, Wisconsin.

The hammers are connected to the rotor in three distinct layers. (Figure 9). The hammers in the top layer are mounted to the shortest **radius;** the diameter to the hammer tips is 33 inches. This layer is the pre-break section of the machine. Here incoming refuse is sufficiently ground to reduce the load to the mill motor. The pre-break section is also the site of ballistic rejection of some potentially damaging and unmillable material.

From the pre-break section, the refuse falls into the constricted neck of the mill, which has a diameter of 41 inches. The hammer tip diameter in this layer is 38 inches. In this section, therefore, there are only 1 1/2 inches of clearance; thus any material that is ungrindable or that has not been sufficiently reduced in size to pass this restriction will be spun around the funnel and will exit through the reject chute opposite the feed opening.

The material then enters the grind section, where the hammers have a 43 inch tip diameter. It is here that most of the work is done to produce the desired particle size. The ground material is discharged centrifugally through an opening at the bottom of the machine (Figure 10).

Two layers of metal form the housing of the mill. The outer layer is the "shell" of the unit. The inner layer is a removable protective lining, upon which are mounted breaker bars. It is the action between the rapidly moving hammers and the stationary bars that produces the grinding.

The hammers are 10x4x1-3/16 inches and weigh 15 lbs. (Figure 11) Originally 54 hammers were used, but this number has been reduced to 34. Reasons for this change will be discussed later.

The Tollemache mill is fed by a metal flight conveyor system shown in Figure 12. The one piece, 45 inch wide conveyor is driven by a 20 hp motor equipped with a speed reducing mechanism and overload switch. The 18 foot long horizontal portion of the conveyor is located in the Gondard storage bin and over approximately one-half the length of the portion of the Gondard feed conveyor lies within the bin. The inclined portion of the feed conveyor is about 30 feet long and makes an angle of about 45° with the horizontal. The variable drive mechanism allows the operator to adjust the conveyor speed from 3 feet/minute to 12 feet/minute. An automatic overload stops the feed conveyor when the mill motor draws 100 percent of its rated capacity. The conveyor restarts automatically after the mill motor draws less than 75 percent of its rated capacity for 5 consecutive seconds.

The conveyor pit is 5 feet deep. At the point where the conveyor leaves the horizontal, the walls abruptly pinch down in width; thus, a constriction is placed on refuse flow. This constriction halts the forward movement of the refuse mass and creates a tumbling or rolling action which, in theory, should produce an even feed to the mill (Figure 13).

Soon after installation of the Tollemache mill, an upgraded method for collecting and hauling the milled refuse to the landfill became a necessity. To meet the increased volume produced by the Tollemache mill, a Heil stationary compactor system was adapted. The stationary compactor is used to compress the ground refuse into a 75-cu. yd. transfer trailer. A 35-cu. yd. storage hopper was installed above the compactor to allow the mill to operate while trailers are being switched (Figure 14, item 6 and Figure 15). The storage hopper is outfitted with an electric eye that automatically turns off the feed conveyor to the mill if the bin becomes full. This system eliminates both spillage from the bin and backups on the final transfer conveyor.

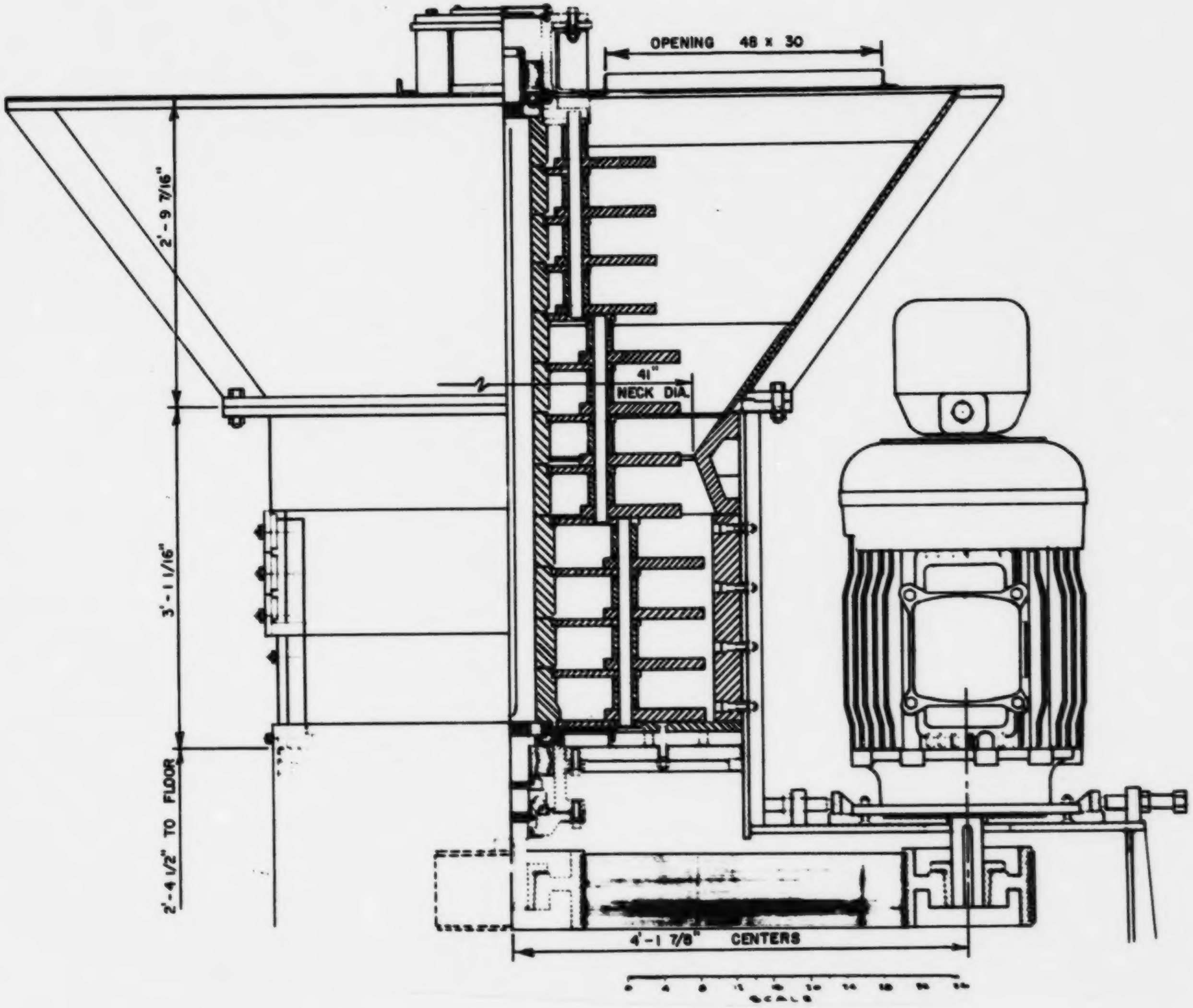

OPENING 48 x 30
2'-9 7/16"
41" NECK DIA.
3'-1 1/16"
2'-4 1/2" TO FLOOR
4'-1 7/8" CENTERS

Figure 9. Cross section of the Tollemache mill.

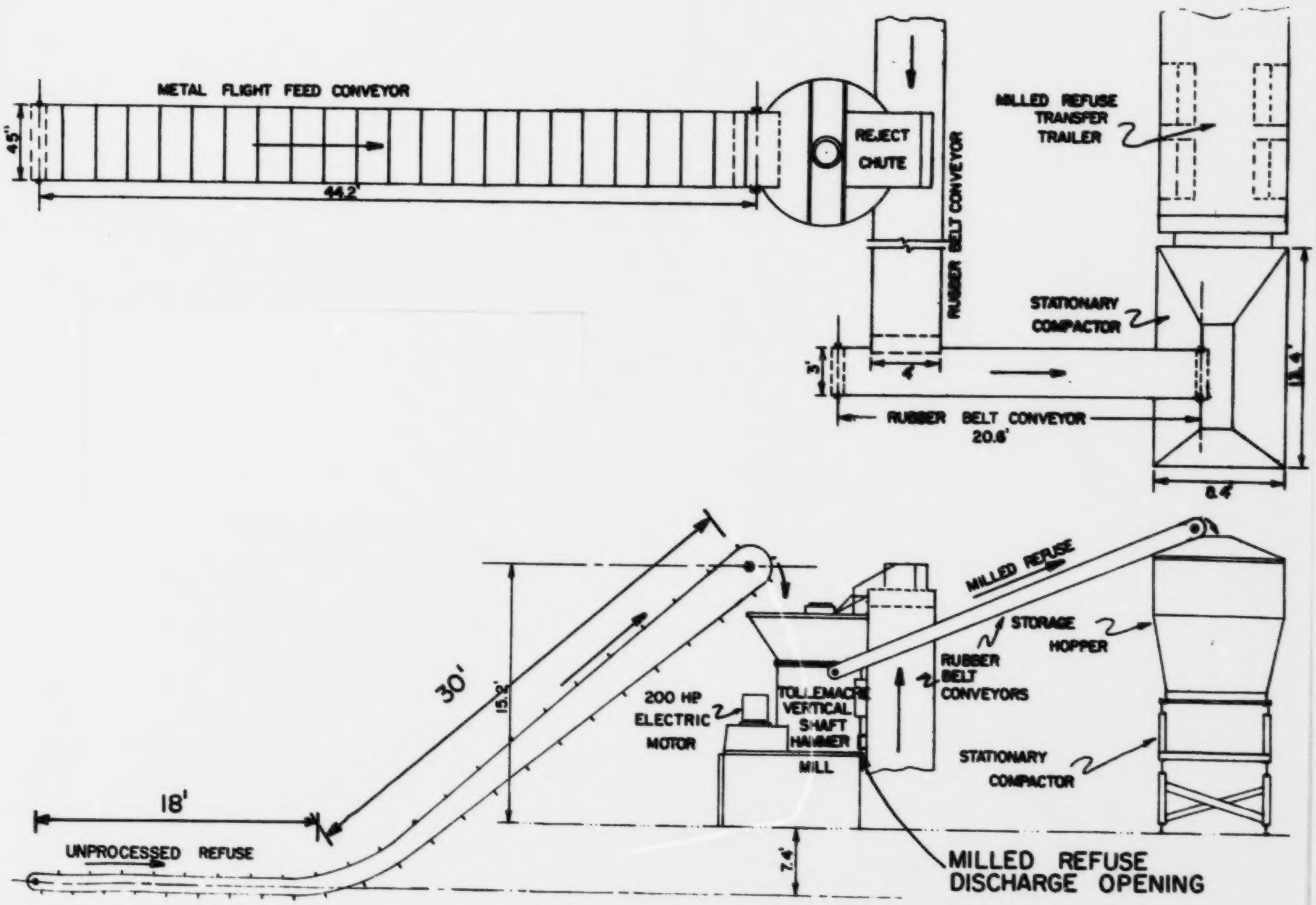

METAL FLIGHT FEED CONVEYOR
45"
44.2'
REJECT CHUTE
RUBBER BELT CONVEYOR
MILLED REFUSE TRANSFER TRAILER
STATIONARY COMPACTOR
3'
4'
RUBBER BELT CONVEYOR 20.6'
13.4'
8.4'
18'
UNPROCESSED REFUSE
30'
15.2'
2.4'
200 HP ELECTRIC MOTOR
TOLLEMACHE VERTICAL SHAFT HAMMER MILL
RUBBER BELT CONVEYORS
MILLED REFUSE
STORAGE HOPPER
STATIONARY COMPACTOR
MILLED REFUSE DISCHARGE OPENING

Figure 10. Overhead and Side views feed and take-away conveyors of Tollemache System.

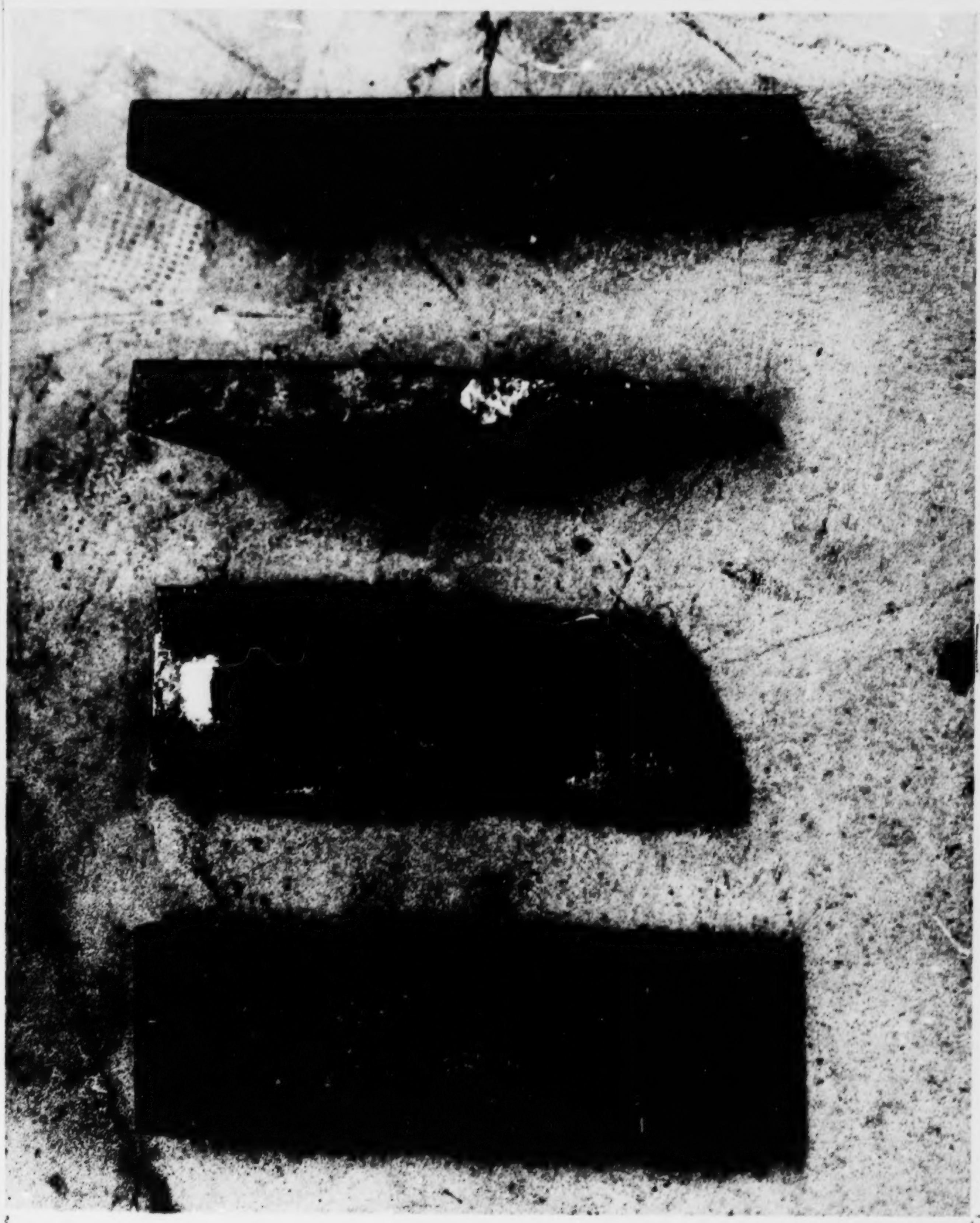


Figure 11. Tollemache hammers; new (either side), and worn, after four days use.

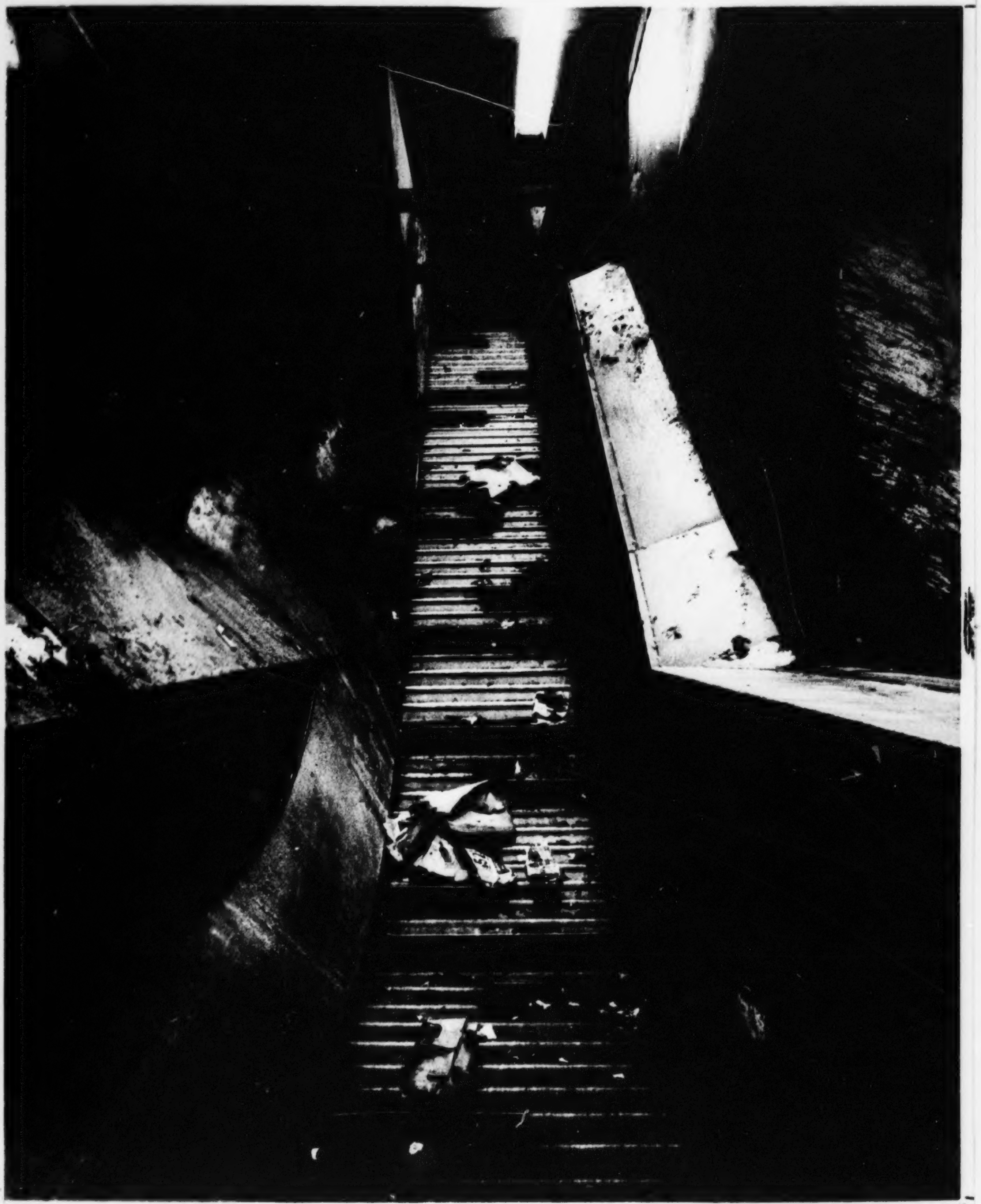
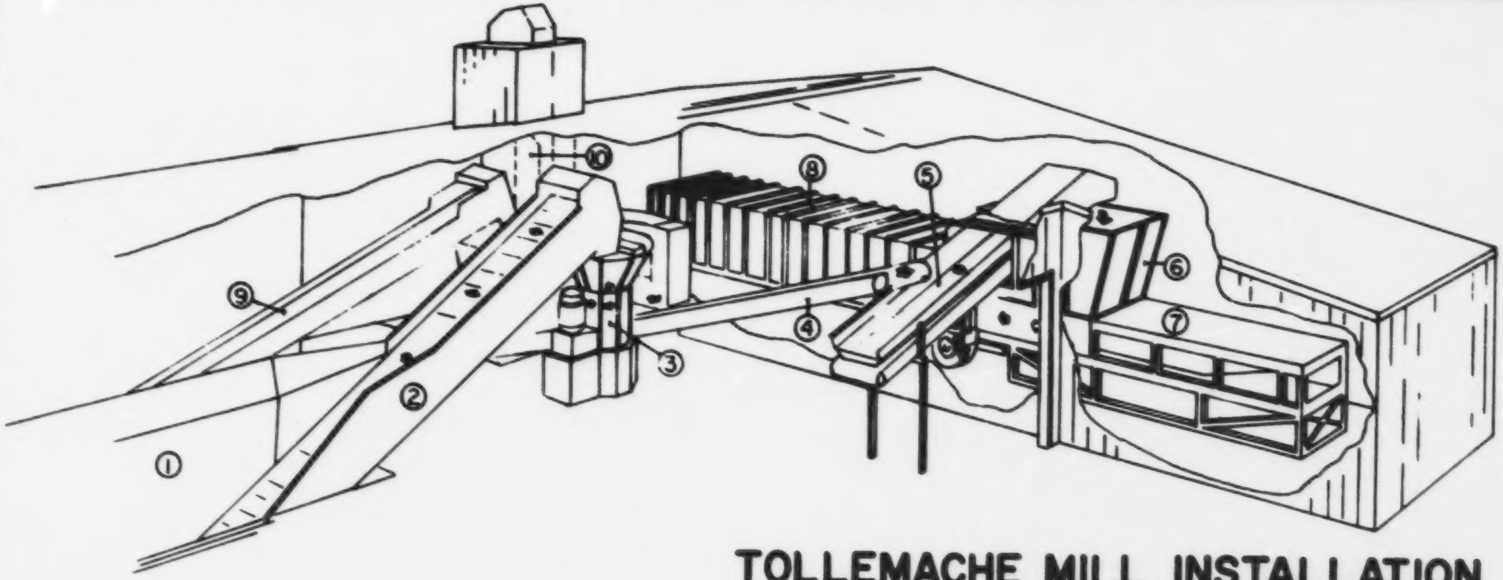


Figure 12. Tollemache continuous-metal-belt elevating feed conveyor.

Figure 13. Tollemache feed conveyor showing tumbling action of refuse.



TOLLEMACHE MILL INSTALLATION
WITH TRANSFER PACKER STATION

① ORIGINAL GONDARD SYSTEM BIN CONVEYOR
② FEED CONVEYOR FOR THE TOLLEMACHE MILL WHICH WAS INSERTED INTO ONE END OF THE GONDARD SYSTEM BIN CONVEYOR
③ TOLLEMACHE MILL
④ 4' WIDE RUBBER BELT CONVEYOR CARRYING MILLED REFUSE FROM THE TOLLEMACHE AND GONDARD MILLS
⑤ 3' WIDE RUBBER BELT TRANSFER CONVEYOR
⑥ SURGE BIN ON THE STATIONARY COMPACTOR
⑦ STATIONARY COMPACTOR
⑧ 75 CUBIC YARD TRANSFER TRAILER
⑨ RUBBER BELT CONVEYOR TO GONDARD MILL
⑩ GONDARD MILL

Figure 14. Transfer Packer Station in Tollemache System.

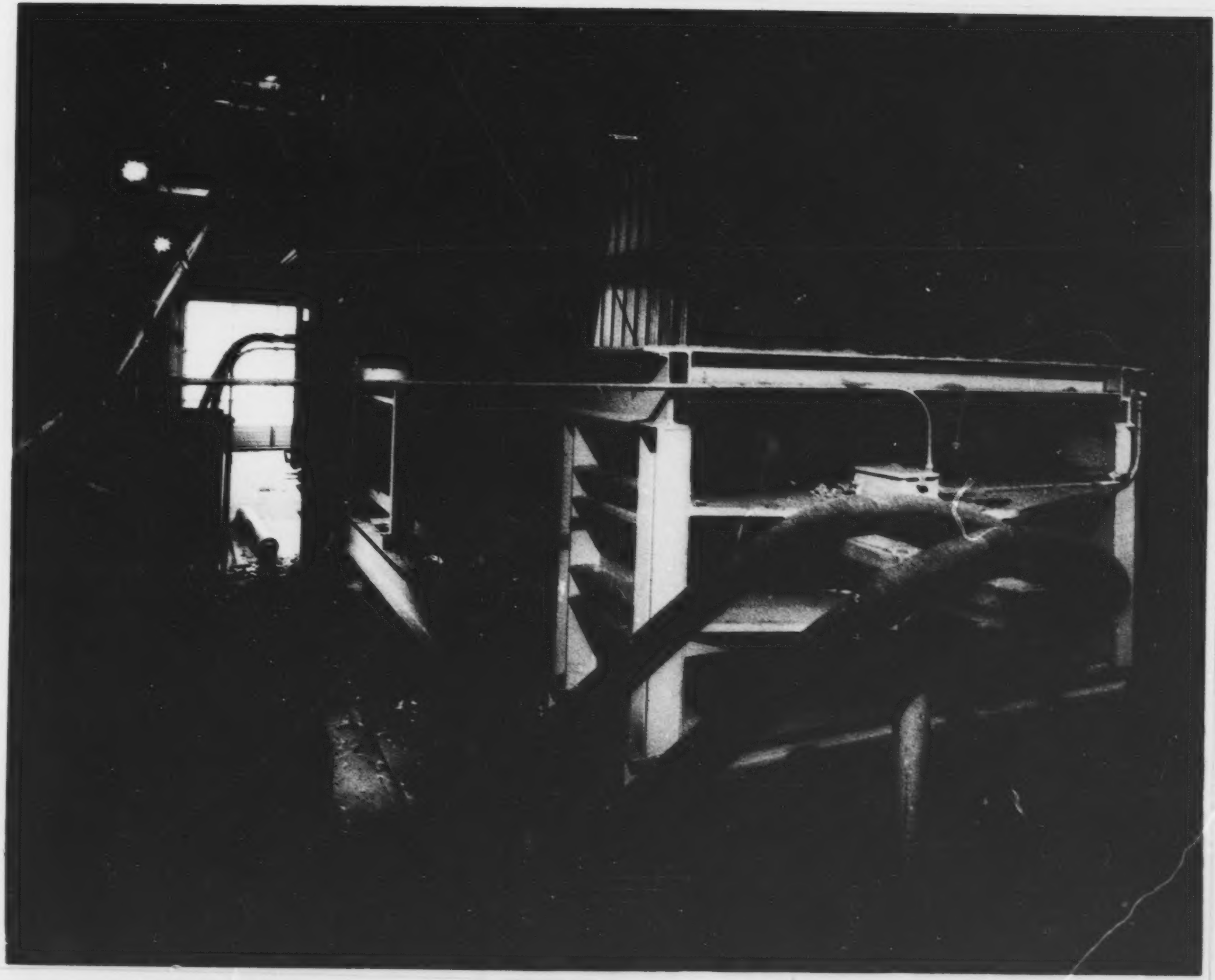


Figure 15. Stationary compactor with 35 cu. yd. storage hopper.

Using the stationary compactor, it takes 70 to 80 minutes to fill one trailer with 16 to 20 tons of milled refuse utilizing one Tollemache mill. One man can switch trailers in 5 minutes. Another 15 minutes is needed to empty and return the trailers if the round trip is less than half a mile. The 35-cu. yd. storage hopper provides enough volume to allow milling to continue during normal switching operations.

Since the plant is located on the landfill site, only two trailers and one tractor were purchased initially. The trailers have a hydraulically operated ram to eject the milled refuse. The rear door operates like a guillotine for filling and swings open for ejection. The Ford tractor is powered by a 266 hp gasoline engine.

In anticipation of hauling milled refuse to outlying landfills (in effect, using the milling facility as a transfer station), Madison has acquired two new tractors and three additional trailers. The new trailers are similar to the original ones except they have swinging gate rear doors and their hydraulic system will be powered by the tractor itself. The new tractors are powered by 195 and 225 hp diesel engines for over-the-road operation.

Problems with the Tollemache Equipment

Experience with the Tollemache conveyor has shown that excessive loading of the conveyor bin is the prime cause of feed delays. Delays result when an empty conveyor is moving no refuse into the mill, or when the conveyor transports unprocessed material in slugs which overburden the mill motor and trip the automatic overload device. Excessive loading of the bin causes bridging of refuse near the constriction where the conveyor leaves the horizontal. Thus, although the bin is full and the conveyor is moving, an inconsistent flow of material is heading toward the mill. To overcome this problem the operator limits the amount of refuse placed in the bin. Although the problem has not been eliminated altogether, the change has reduced delays and led to a smoother operation.

Other problems with the conveyor included failure of a linkage in the speed reducer and occasional jamming of the belt when objects became lodged between the conveyor rollers and track. The linkage problem was traced to excessive wear of the reducer assembly and was quickly eliminated by an overhaul of this assembly. Some of the difficulties experienced with the speed reducer are thought to have been due to the original design. The manufacturer has redesigned subsequent models of the speed reducer to eliminate the problems encountered at Madison.

The jamming problem, which occurred three times in 1971-72, caused the rollers to jump the tracks, resulting in damage to the bin walls, conveyor flights, and belt tighteners. The problem centered at the point where the Tollemache conveyor makes a 180° turn at the center of the Gondard bin. A steel "umbrella" was built over the turn early in 1972, and no further jams of this kind have been reported.

The stationary compactor has been relatively trouble free. Some metal fatigue has been noticed on the tracks supporting the ram and also on the floor of the hopper. The most serious problem was a leaky hydraulic cylinder which operates the hook that holds the trailer to the hopper. On two occasions the cylinder failed, thus releasing the trailer. The result was that the ram pushed the trailer forward and eventually through the door of the packer room. The cylinder was replaced and no further difficulties have been experienced.

The main problem with the original tractor in the haul-away system for the Tollemache mill has been its gasoline engine. Mainly, the motor does not have sufficient torque at low speeds, thus making it hard to operate with a full trailer. Some engine overheating problems, caused by the radiator becoming clogged with dust, have also plagued the tractor. Constant maintenance of the radiator is needed to keep it open and prevent engine damage.

The mill itself is the most reliable piece of equipment in the Tollemache system. Nonetheless, the mill has not been completely trouble-free. Some problems have included internal jamming, explosions, and trouble with the radial and thrust bearings on the main shaft.

Internal Jams:

An internal mill jam differs from a feed jam in that it occurs in the mill proper, usually in the grind section. Such jams have occurred when heavy wire, bed springs, tires, etc. inadvertently enter the machine. When this happens the mill motor becomes overloaded and circuits are broken. The jams, especially when wire was involved, have stopped operations up to an hour while the machine was being cleared.

During the first few months after installation, these jams occurred about once a week. Thus, elimination of this problem was of importance. Prevention has involved close scrutiny of incoming refuse. Any article deemed damaging or able to cause jams is removed from the incoming stream of refuse. This material is small in quantity and is landfilled and covered with the milled refuse. Also, since Madison has a bulky item pickup, refuse pickers are instructed not to collect potentially damaging articles. The combination of minor separation at the plant and separation on the collection routes has minimized internal jams to the point that, on the average, only one is experienced a month.

Explosions:

As the refuse is being processed a constant array of sparks is produced by contact of the hammers and metal in the refuse. Therefore, if a can of paint thinner, unbroken bottle of alcohol, or a container with any other flammable liquid happens to enter the mill intact, an explosion is possible. The explosions themselves do no notable damage to the mill, but they are a potential hazard to personnel working in the area. During the first 3 years of operation using the Tollemache mill, five or six such explosions occurred. After the first two incidents, an explosion chamber was constructed above the mill. The chamber consists of a heavy steel chute leading from the top of the mill to the plant roof. Here the chute is capped with light sheet metal to provide minimum resistance to rapidly expanding gases. The expanding gases from an explosion are vented through the roof. Experience has shown that the explosion chamber functions quite well.

Bearing Problems:

By far the biggest concern in respect to the mill itself has been the bearings that support the rotor. At the extreme upper and low parts of the rotor are three bearings. Two are radial bearings; the other a thrust bearing. It has been the unfortunate experience at Madison to have to replace two lower radial bearings and four thrust bearings.

In the original design, the thrust bearing was to draw the cooling and lubrication oil from a reservoir and throw it up to the two radial bearings. About a year after installation, the thrust bearing burned out and was promptly replaced. The replacement bearing was manufactured in the United States and was not exactly the same as the original manufactured in England. Less than a week after replacement this new bearing also burned out, as did a radial bearing. At this time it was decided that the new type bearing was not drawing enough oil to cool itself and consequently not passing enough up to the radial bearings. Thus, an oil pump was installed to force-circulate oil to all bearings. This worked well until about a year later when the thrust bearing again needed replacement. It was replaced and burned out 3 months later, as did another radial bearing. At this point a careful reevaluation of what had taken place over the last year and a half revealed that the problem was not directly related to the circulation of oil but was the result of the rotor shaft moving up and down. During replacement of the rotor, it was discovered that a retainer nut holding the rotor assembly together had worked loose, thus allowing the entire rotor assembly to jump up and down a fraction of an inch. This resulted in abnormal stress on the bearings, and they burned out. A key has been placed over the retainer nut in the new assembly, and no bearing problems have been experienced since that time.

Tollemache Operation and Production

The Tollemache feed conveyor is a substantial improvement over the system used in the Gondard operation. While the Tollemasche conveyor was not originally designed for transporting refuse, it has performed adequately during evaluations at Madison.

Unlike the Gondard mill with its grates, the Tollemache mill depends on the number, length, and pattern of hammers to produce the desired particle size. The original pattern used in England and initially tried in Madison involved 54 hammers. After a short period of test runs it was evident that such a pattern did not meet the objectives of milling for landfill disposal. The product was more suitable for a composting operation, and production rates were very low. Numerous modifications were then attempted. A final pattern involving 34 hammers emerged as the most efficient for Madison's purposes (Figure 16). This pattern yields an average operational production rate of about 14 tons per hour, or just one ton per hour below the manufacturer's indicated capacity.

As with the Gondard mill, two production rates were determined for the Tollemache mill. These are the operational rate (including only time during which refuse is being milled) and the overall rate (including time during which mill is milling plus down time due to mechanical problems in the plant). During test periods, the operational rate of the Tollemache mill ranged from 11 to 20 tons per hour. The overall production rate has been about 0.5 tons per hour lower than the operational rate, indicating that the machine operates with a minimum of down time.

A distinct seasonal variation in production rate has been noticed at Madison which is related to the moisture content of the refuse. During late spring, summer, and fall, when the average moisture content of the refuse ranges from 35 to 45 percent on a dry weight basis, the highest production rates have been experienced. In late fall and winter, when the moisture content is only 15 to 20 percent, production rates reach a minimum.

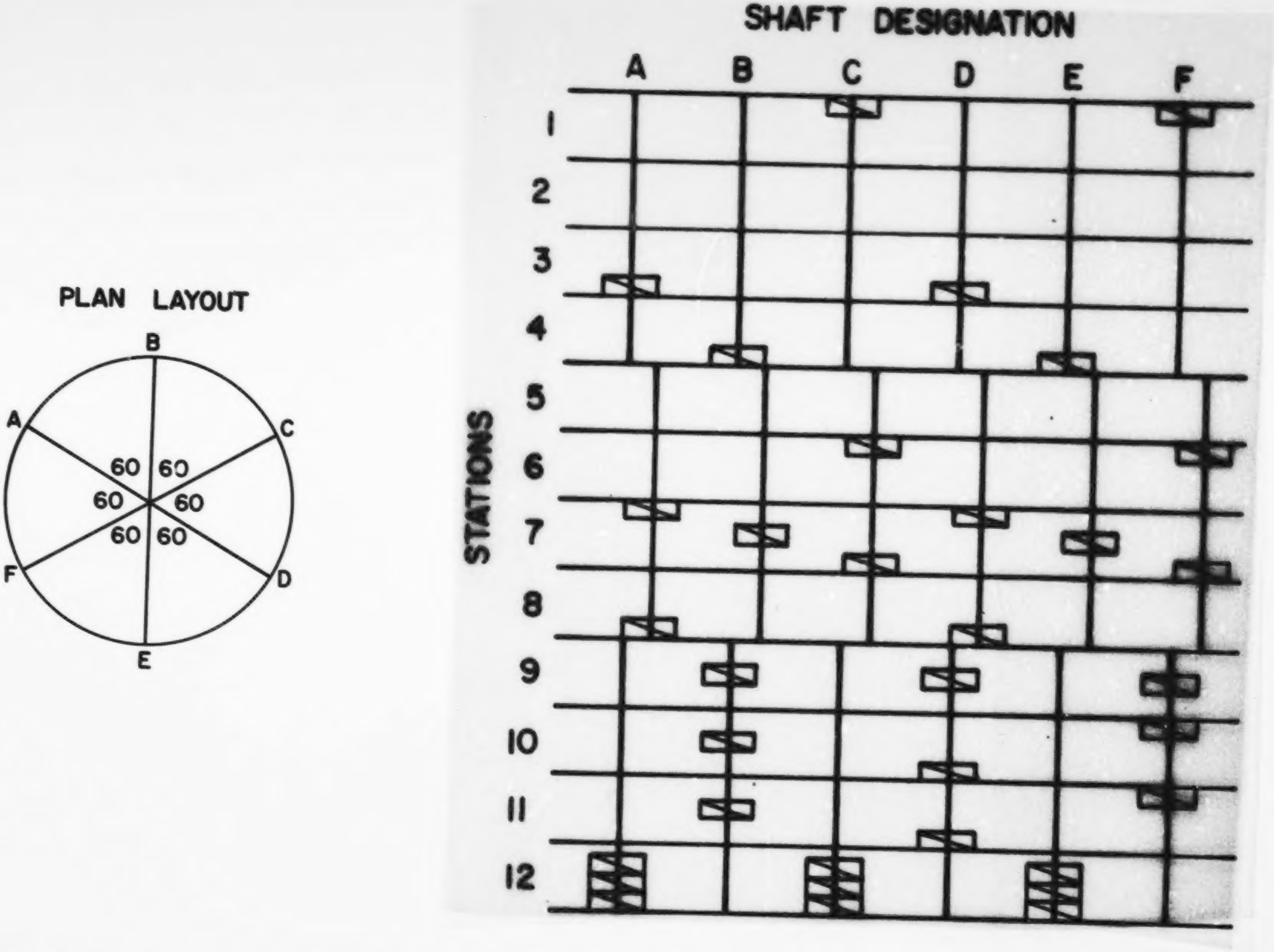

PLAN LAYOUT
A
B
C
D
E
F
60
SHAFT DESIGNATION
A
B
C
D
E
F
STATIONS
1
2
3
4
5
6
7
8
9
10
11
12

Figure 16. Tollemache hammer pattern in use at Madison at end of evaluation period (June 1972).

This fact was brought out during two evaluations of the mill. One was done during the summer and early fall of 1970, the other during the winter of 1971. Table 3 shows a compilation of production rates on a monthly basis for the two test periods. Monthly average moisture content is also indicated.

The table shows that higher production rates were achieved during the period of high moisture contents. Thus, when discussing mill production rates, the figures should be cited in terms of dry tons of refuse per hour. In this manner rates can be calculated for different applications in other parts of the country. For this reason, Table 4 is presented using dry tons milled and computing a production rate in units of dry tons/hour.

A comparison of dry tons per hour in Table 4 shows that the mill processes refuse at nearly constant rates and that, in fact, the seasonal variations are due to moisture content changes.

Tollemache Power Consumption

Mill power consumption is broken down into two distinct categories--kilowatts (kw) and kilowatt hours (KWH). Kilowatts provide a measure of peak demands for power during a specific time period. Kilowatt hours are a measure of the actual energy usage. As such, kilowatts are not a function of tons milled, but kilowatt hours are.

Mill demand ranges from 110 to 160 kw/month. The highest values are experienced from November to March; but since the cost of demand at Madison is billed on the highest demand experienced in the preceding 12-month period, the range of demand is not important at this site. Energy usage measured in kilowatt hours/ton (KWH/T) follows much the same pattern, peaking in the winter and reaching lows during late spring, summer, and early fall.

Extensive power data were kept during two experimental evaluations of the Tollemache mill. Table 5 shows the summaries of data collected during these periods. Notice that energy usage during the summer evaluation was 2.5 KWH/T lower than during the winter tests. Also notice that on a dry-ton basis the summer evaluation had a power consumption over 2.1 KWH/T lower than the winter test. Thus, a definite positive relationship between KWH/T and moisture content is not evident, as was the case when computing production rates; in fact these data suggest an inverse relationship where power consumption increases as moisture content decreases.

Mill accessories, including feed conveyor, final transfer conveyor, stationary compactor, welding machine, etc., all operate from a three-phase, 440-volt source. No equipment was available to secure power data from the accessories on an individual basis until January 1972, when a single power meter was installed to record data from the stationary compactor. Prior to that time, all accessories had been lumped together. Data from both evaluations has indicated that power consumption for mill accessories as a whole is about one-fourth that of the mill itself.

Two-Mill, Two-Shift Operation

Plans for expanding operations at the Madison Refuse Reduction Plant in order to operate on a two-shift basis were begun in the summer of 1969. The first step toward this goal was taken in the winter of 1970-71 with completion of the plant expansion. The second step was completed with the conclusion of the second and final Tollemache evaluation early in 1971.

TABLE 3

OPERATING AND OVERALL PRODUCTION RATES FOR TOLLEMACHE MILL

Test Period	Tons Milled	Time (Hours) Operating	Time (Hours) Overall	Prod. Rate (TPH) Operating	Prod. Rate (TPH) Overall	Moisture Content Dry Weight
July 6 to 31, 1970	1480	100.4	104.0	14.72	14.22	33%
August 1970	1573	104.9	107.7	15.01	14.62	35%
September 1970	1701	122.5	125.3	13.89*	13.58*	44%
October 1 to 9, 1970	564	38.0	38.3	14.82	14.72	32%
July 6 to October 9, 1970	5318	365.8	375.3	14.53	14.18	37%
February 4 to 28, 1971	1105	86.40	87.06	12.79	12.69	25%
March 1 to 31, 1971	1519	118.11	121.61	12.86	12.50	22%
February 4 to March 31, 1971	2624	204.51	208.67	12.83	12.58	23%

* During two periods in September, linkage on the variable speed drive of the mill conveyor was broken. Thus, the conveyor could only operate at its slowest speed. This was a feed problem, not a mill deficiency.

TABLE 4

OPERATING AND OVERALL PRODUCTION

Test Period	Dry Tons Milled	Dry Tons per Hour Operating	Dry Tons per Hour Overall
July 6 to 31, 1970	1110	11.05	10.67
August 1970	1165	11.11	10.82
September 1970	1180	9.64*	9.43*
October 1 to 9, 1970	425	11.19	11.10
July 6 to October 9, 1970	3880	10.61	10.35
February 4 to 29, 1971	885	10.25	10.18
March 1 to 31, 1971	1245	10.55	10.25
February 4 to March 31, 1971	2130	10.40	10.20

* During two periods in September, linkage on the variable speed drive of the mill conveyor was broken. Thus, the conveyor could only operate at its slowest speed. This was a feed problem, not a mill deficiency.

TABLE 5

COMPARISON OF POWER DATA FOR TOLLEMACHE MILL ALONE (1970-71)

Period I	KWH	Tons Milled	KWH/Ton	Dry Tons Milled	KWH/ Dry Ton
July 6-31	10672	1480	7.20	1110	9.60
August	9856	1573	6.26	1165	8.46
September	10288	1701	6.04	1180	8.70
October 1-9	3152	564	5.59	425	7.42
Overall	33968	5318	6.37	3880	8.75
Period II					
February 4-28	10272	1105	9.30	885	11.60
March 1-31	12864	1519	8.46	1245	10.31
Overall	23136	2624	8.82	2130	10.86

The third phase of the plan was attained by December 1971 when a plant supervisor and three additional men were hired to man the second shift. Finally, in January 1972, the two-shift operation utilizing both the Gondard and Tollemache mills was initiated. This section of the report deals with observations and evaluations of this operation between 1 January and 30 June 1972.

During the initial five years of operation, three men performed all plant functions. Supervision was provided on a limited basis from the Madison Street Department. During evaluations of the combined Gondard and Tollemache systems, it was concluded that three men were sufficient to handle plant operations. Thus, when preparations for two shifts were made it was decided that three additional men would be hired to man the night shift.

In addition, a full-time supervisor was employed. It was hoped that the increased labor cost in hiring a seventh man would be offset by increased plant efficiency. This seems to have been a valid assumption.

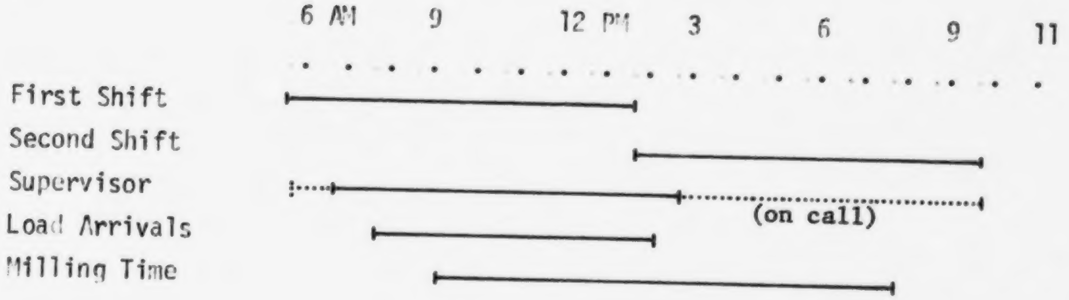
The supervisor is responsible for personnel and administrative duties not ordinarily assigned to an employe in this position. In addition, he performs some of the public relations tasks at the milling plant. Thus, while the supervisor's salary is assigned to mill operations, about half of his duties are not directly production related.

Table 6 shows the prescribed duty hours for each shift and the supervisor. Also included in the table is the average time span for load arrivals and average mill operating time. The average length of the milling day is 10.5 hours (10:30 AM to 9:00 PM).

TABLE 6

HOURLY BREAKDOWN OF AVERAGE DAY

(Two-Mill, Two-Shift Operation)



Packer trucks deposit their loads over a 6.5 hour period each working day. However, the trucks usually arrive in bunches at three specific times during that period--middle morning, noon, and midafternoon. Thus it is not uncommon for 10 or 12 trucks to be lined up at one time waiting to enter the plant. By union agreement, packer crews cannot start at staggered times. Another factor contributing to this problem is a floor plan that will permit only two trucks to maneuver inside the plant at one time. This problem does not affect plant operations but does lower packer crew efficiency. One benefit derived from the situation is that the front-end loader operator does not have a continuous supply of unprocessed refuse to stack or move, thus allowing him free time to perform other duties.

On an average day, 53 loads (190 tons) are handled at the plant, although as many as 72 loads (340 tons) per day have been processed. These figures represent the entire city's collection and that of some private collectors (3 to 6 loads per day). In 1972, approximately 46,600 tons of refuse were milled in the two-mill, two-shift operation at Madison. It is important to note here that all the residential and light commercial refuse collected by city crews is now being milled. Bulky items, brush, and bundled newspapers are being collected separately and are not milled. The bulky items and brush are landfilled separately, while newspapers are recycled.

Mill start times must be planned to avoid production stoppages due to lack of material. After detailed investigations, the plant supervisor concluded that a lag of 1.5 hours between first load arrival and mill start time eliminates almost all production stoppages due to material shortages.

In the design of the two-shift operation it was estimated that an average of 280 tons of refuse could be processed per 13 to 14 mill-hour day at a rate of 20 to 22 tons per hour. During the first 6 months of 1972 an average of nearly 190 tons of refuse was milled per 10.4 mill-hour day at 18 tons per hour. Although short of design estimates, these figures are satisfactory for early stages of operation.

Two causes were responsible for the difference between the design and actual figures. First, during the initial 3 months of operation, refuse generation was at its seasonal low. Second, mill down time, near 2.8 hours per 10.4 operating day, was quite high. Efforts are underway to increase available tonnage by bringing in privately collected refuse and to decrease down time by improving equipment maintenance and by making more effective use of plant personnel.

During individual experimental runs of the Gondard and Tollemache mills, operating and down times were recorded separately. Since this method would prove difficult in simultaneous operation, simple strip-chart recorders were installed to measure operating and down time for each mill. The recorders keep track of mill motor amperage on a continuous time chart. Thus it is possible to determine when the machines are running as well as the level of loading. For this operation, all times above "mill idle" are productive, all other times are considered down time.

Operation and overall production rates for the first 6 months of 1972 are shown in Table 7. Refuse moisture content as presented is computed on a dry weight basis. Also included in this table are production figures for the second half of 1972, following the evaluation period.

Table 7 shows a general increase in tons milled during the 6 month evaluation period. This increase was due largely to seasonal variations in refuse generation in the city. The table does not show that daily operating time went from 7.7 hours in January to 13.1 hours in May. A ratio of down time to operating time indicates that March had a high of 0.39 hours of down time for every hour of productive operation. This figure was decreased to 0.25 by June.

Although production for the two 6-month periods of 1972 was virtually equal, overall TPH went from 17.90 in the first 6 months to 19.47 in the second 6 months. Also down time decreased from 350 hours in the first half of the year to 213 in the second half.

TABLE 7

OPERATIONAL AND OVERALL PRODUCTION RATES (1972)

(Two-Mill, Two-Shift Operation)

	Tons Milled	Hours[1] Plant Time	Hours[2] Down Time	Overall[3] Rate (TPH)	Operational[4] Rate (TPH)	% Moisture Content	Dry Tons	Overall Rate (Dry TPH)
January	2663	161	26	16.51	17.93	23	2165	13.44
February	3334	205	39	16.28	17.93	23	2710	13.22
March	3440	208	74	16.51	20.00	25	2752	13.24
April	4236	235	77	18.04	21.98	29	3287	14.00
May	5126	262	77	19.57	22.86	40	3665	14.00
June	4518	232	57	19.48	22.24	38	3276	14.15
Overall for January-June 1972	23317	1303	350	17.90	20.63	31	17855	13.71
July*	2165	130	51	16.64	22.49			
August	4947	232	37	21.32	23.17			
September	4797	230	31	20.83	22.44			
October**	3040	163	26	18.61	20.16			
November	4840	243	29	19.91	21.74			
December	3483	197	39	17.72	19.23			
Overall for July-December 1972	23272	1195	213	19.47	21.72			
Overall for 1972	46589	2498	563	18.65	21.22			

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* Low production because density tests conducted at landfill diverted considerable unprocessed refuse.

**Low production because rotor was being changed on Tollemache mill.

1. Elapsed time from first mill start-up to last mill shut-down including milling plus down time.
2. Summation of hours down time for Gondard mill plus Tollemache mill.
3. Tons milled/hours milling plus down time.
4. Operating rate is defined by the following formula for a two mill facility, to take into account the different milling capacities for the two mills:

$$\frac{(22\ \text{tons/hr}) \times \text{Tons Milled}}{(\text{Tollemache operating hours} \times 14\ \text{tons/hr}) + (\text{Gondard operating hours} \times 8\ \text{tons/hr})}$$

The data in Table 7 also show an increase in production rates from January to June. Although this production rate increase reflects improving plant operation, it is more directly related to an increase in refuse moisture content. Figures showing the operational rates in terms of dry tons per hour (DTPH) illustrate this dramatically. The maximum variation from the overall figure of 13.71 DTPH is only 0.49, while the maximum variation in the wet basis average of 17.90 TPH is 1.67.

Power usage (KWH) was recorded by a 440-volt watt-hour meter installed in February 1972 on each mill(Table 8).

TABLE 8

POWER CONSUMPTION - MILLS COMBINED (1972)

	Demand (kw)		Combined Energy	KWH/	KWH/
	Tollemache	Gondard	Usage (KWH)	Ton	Dry Ton
March	131	138	31770	9.28	11.56
April	125	134	31157	7.38	9.47
May	116	121	31950	6.23	8.40
June	120	116	29730	6.60	9.07
OVERALL				7.19	9.61

From the table it is seen that the Gondard mill created slightly more power demand than the Tollemache mill in all months except June. Previous evaluations of the separate mills showed that the Gondard mill used nearly as much energy as the Tollemache mill even though it is rated at only about 60 percent of the capacity of the Tollemache.

Earlier tests indicated that the Gondard mill consumed power at the rate of 12.5 KWH/ton while the Tollemache mill used only 7.2 KWH/ton on the average. The combined overall figure of 7.19 KWH/ton in Table 8 is better than the average of either machine on previous evaluations. It should be noted, however, that the 1972 data were collected during a period of the year which in the past has recorded the lowest power consumption. On a dry-ton basis, the overall combined figure was 9.61 KHW/dry ton. No apparent relationship exists between moisture content and power consumption, as in the case of moisture content and production.

On the basis of the first 6 months of the two-shift operation, it would be unrealistic to assume that an average of 280 tons of refuse could be milled daily at this stage. Not only would it require 13 to 14 hours of mill operation daily, but it would also mean that the Gondard mill would be in operation at an overall production rate of 7 to 8 tons per hour and the Tollemache at 13 to 14 tons per hour -- a combined overall production rate of 20 to 22 TPH. Table 7 shows that during no month of the evaluation was an average production rate of 20 TPH achieved. Even if 19.57 TPH, the highest monthly rate obtained during the period of record, were to be maintained all year, it would require 14.3 hours of mill operation per day to maintain a daily output of 280 tons. This would leave only 1.7 hours for clean-up and preventive maintenance, an insufficient time for such tasks. It is more realistic to assume that under the present conditions of a 12 to 13 hour milling day, at an average of 18 to 19 TPH, a production of 230 tons per day could be achieved and maintained.

The two-shift operation involved new personnel and new operating characteristics during the evaluation period. Thus it is fair to say that the system was not operating at its full potential. This is evidenced by the high incidence of down time during this evaluation compared to down time experienced during evaluations of the two mills separately. It is reasonable to expect, therefore, that the plant will eventually reach a production rate of 20 TPH over the year. Combined with a 12 to 13 hour milling day, this would result in an average daily production of 240 tons or a yearly average of 60,000 to 65,000 tons.

Mill Accessories

For this evaluation, mill accessories are defined to include feed and takeaway conveyors as well as welding equipment. This equipment operates from a 440-volt power source, and power consumption for the accessories, therefore, was determined by taking the difference of the total 440-volt usage and the 440-volt usage of the two mills. From this information, it was found that average accessory demand is only 7 percent of the total for both mills and energy usage is 18 percent of total energy usage for both mills. Thus, mill accessories required approximately 1.29 KWH/ton or 1.34 KWH/dry ton of electrical energy.

With simultaneous operation of both mills, an increased demand on the stationary compactor has occurred. It now takes only 45 to 60 minutes to fill one 75-cu. yd. trailer. The 35-cu. yd. storage hopper thus does not provide enough volume to allow milling to continue during normal trailer switching. The mills in combined operation fill the bin in 2 to 5 minutes, while it normally takes 5 minutes to switch trailers.

A watt-hour meter was installed on the power source to the stationary compactor in February 1972. Adequate data were not obtained until April. For the period of April through June, the monthly average power consumption of the compactor was 0.76 KWH/ton (1.03 KWH/dry ton), or about 3500 KWH. Thus, the compactor requires less than 10 percent of the power needed by the mills and their accessories.

Maintenance Programs

Preventive maintenance on the conveyor is done once a week. At this time the pulleys are greased and the tracks oiled. A general inspection to locate worn parts or potential trouble areas is also conducted to minimize major breakdowns and to plan an effective repair program.

With the Gondard mill, the hammers, of course, are subject to the greatest abrasion in the system. The rods on which the hammers swing require replacement about four times per year when the mill is operating on a one-shift basis. The spacers between the rotor disks have a similar lifespan. Other erodable elements are the grates and the liner or wear plates. These are maintained by arc-weld applied hard surfacing. The maintenance program, when properly executed, can be carried out daily during the clean-up period. Only if grate replacement is required should it be necessary to perform such work on overtime. The fact that all elements of the Gondard hammermill are relatively thick and can be welded in the down-hand position makes it easy to train personnel for this work.

Routine maintenance performed on the Tollemache mill mainly involves hardfacing and/or replacing hammers and mill liners and replacing shafts. Other areas of the machine, such as reject chute, rotor plates, and cone liners, need only occasional attention.

Hardfacing of hammers and mill liners will be discussed later. The vertical shafts, 16.5 in. in diameter and 23 ft. long, hold the hammers and therefore also suffer considerable wear. Experience has shown that approximately four of the ten shafts in the mill need replacement per set of hammers. Shafts are replaced when daily inspections reveal excessive wear or that a shaft is bent.

Two-Mill Operation:

There is a 3 1/2 hour period between arrival of first-shift personnel and mill start time under the current operation at the Madison Refuse Reduction Plant. This time is used for necessary plant clean-up and to conduct the preventive maintenance program.

Detailed inspections are performed on Mondays. At this time notes are made on what repairs or replacements are needed (Figure 17). The necessary work is then scheduled for completion later in the week. Necessary lubrication is also applied during Monday inspections. Hammer "tipping" or hardfacing is performed daily. Portions of the mill interior are hardfaced as necessary.

Hardfacing:

The original recommendation for the Gondard mill was to use plain carbon steel hammers and to replace them after reversing them to use both outer faces. Following this procedure only about 300 tons of refuse could be milled with one set of hammers. Therefore, experiments with hardfacing, or "tipping", the hammers with arc-deposited metal were begun in February 1968. Results of tipping medium-hard steel (SAE 1060) hammers were extremely good -- hammer life was nearly doubled. Early attempts to tip harder (SAE 1090) hammers resulted in frequent fractures, but recent experience has been more successful. Nearly 1500 tons can now be milled with one set of properly tipped hammers in the Gondard mill.

Because of the success of the hammer tipping program with the Gondard mill, a similar but more intensive hammer maintenance regimen has been in force with the Tollemache system since its installation. This program involves application of Amsco Super 20 hardfacing alloy to each hammer before mounting it in the mill. The hardfacing alloy is applied to the wearing edges of the hammer. The wearing edges are in constant contact with the refuse and consequently deteriorate more rapidly than other surfaces of the hammer. In addition to the initial tipping, 18 hammers in the lower section of the mill are tipped daily. The remaining 16 hammers in the pre-break and neck sections of the mill are inspected daily and tipped when needed.

In full-scale operation, a set of 34 Tollemache hammers maintained by tipping will process 1,000 to 1,200 tons of refuse. A set of untipped hammers will process 400 to 500 tons. From this comparison, it is obvious that tipping greatly increases hammer life; but it was not evident that tipping is economical. To study the economics of tipping, a test was performed using tipped and untipped hammers in the mill under normal operating conditions. The comparison was made on a cost-per-ton basis, and the results showed that a tipping program, rigorously applied, will save approximately 23 cents per ton of refuse milled. The entire savings is due to the lower number of hammers required. Labor and welding materials for the tipping program were about equal to labor for hammer changing alone in the control program using untipped hammers.

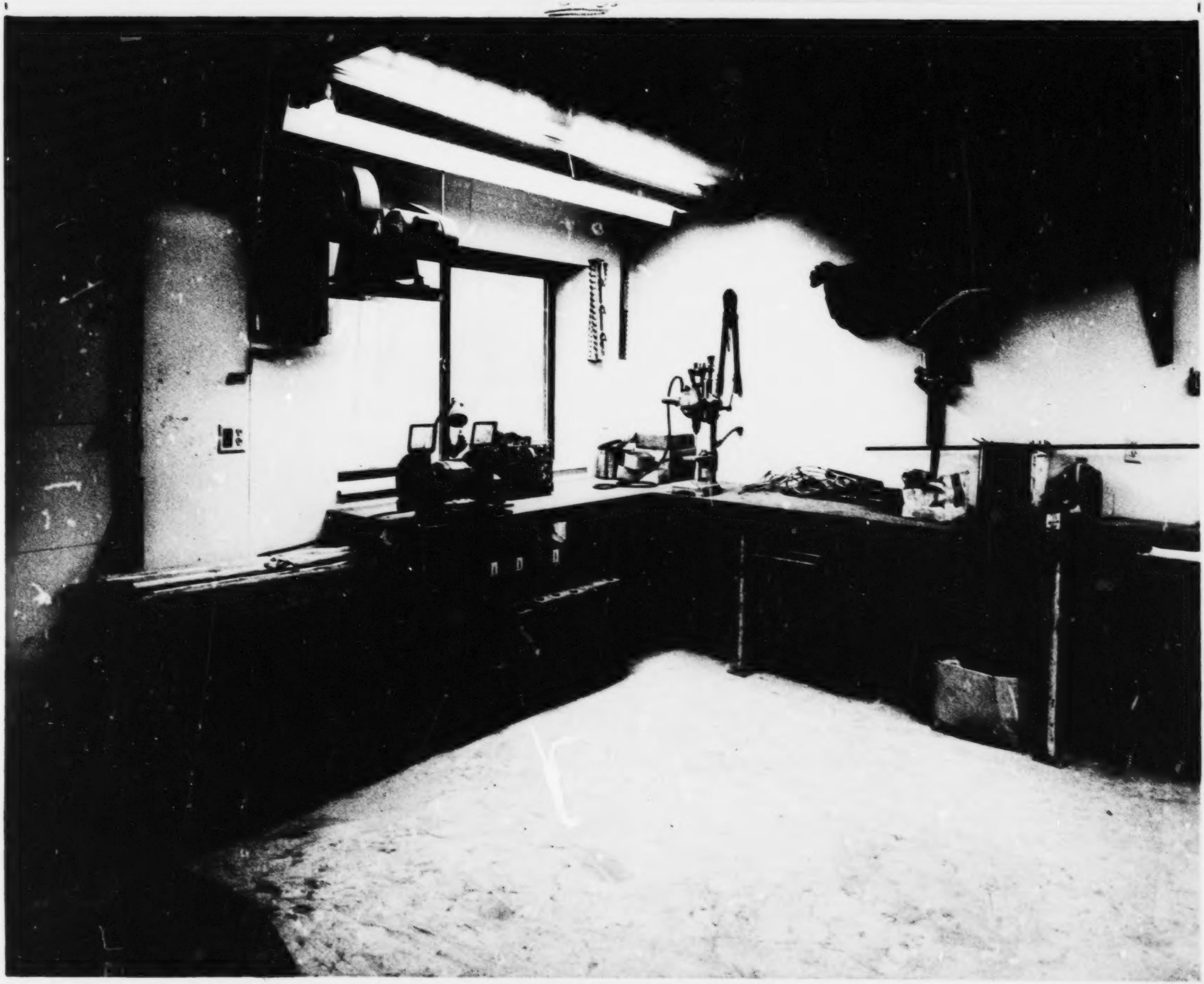

Figure 17. Maintenance shop for welding and repairs at Madison's milling plant.

The hull of the Tollemache mill is protected by replaceable manganese steel liners or wear plates. During the first 2 years of operation, no attempt was made to reduce wear of these liners because they did not show significant loss of metal. A set of untipped liners was found to last through approximately 12,000 tons of refuse. When the plant went to a two-shift basis in January 1972, the prospect was for the Tollemache mill to process 45,000 tons of refuse annually. At that rate of production, four sets of liners would be needed each year. At over $1,300 per set of liners and with 32 man-hours of labor needed per change, the outlook suddenly became expensive. Consequently, methods of increasing liner life were investigated. The first method tried was hardfacing. Some difficulties were experienced, however, since an adequate welding rod that would deposit weld vertically was needed. After trying many types of rods, a Stoody 3/8 in. #57159 proved most efficient. Liners are now extensively hardfaced prior to installation and are touched up in the machine when extensive wear is noticed. Early results indicate that this procedure has increased liner life to 20,000 tons per set. Other methods to increase liner life are now being studied, such as rotating or inverting them periodically to distribute wear evenly and welding manganese rods to the liners to prevent wear of the base metal itself. Also, the manufacturer has redesigned the liner plates to give extra thickness on the lower half of the plate.

LANDFILLING MILLED REFUSE

To provide a direct comparison between landfill milled refuse without daily cover and the sanitary landfill technique using the unprocessed refuse, refuse was placed in piles -- called cells -- above the level surface of the Olin Avenue landfill site during 1967 and 1968 (Figure 18). The cells were 5 to 6 feet in height and were levelled and sloped to provide surface drainage. Lengths and widths varied, but the smallest cell was at least 40 feet in its shortest dimension (Figure 19). Covered unprocessed cells and uncovered milled cells were constructed simultaneously. Records were kept on the season during which the more than 20 cells were constructed and (for milled refuse) grate size used in the mill (Table 9). Both cell types were compacted with a D-7 Caterpillar tractor. In the case of covered cells, the cover material was a sandy silt obtained five miles from the site.

Strictly speaking, those cells constructed with unprocessed refuse and covered were not sanitary landfills. Insufficient refuse was available to construct an entire cell, or even a major portion of a cell, in a single day. A choice had to be made, therefore, whether to cover the small amount of refuse placed each day, cover all exposed refuse daily except for the working face, or cover each cell upon its completion. It was decided to avoid having the cells consist of small pockets of refuse bounded by soil, because this would lead to difficulties in tracing and understanding moisture and gas movement. But it would have been poor practice to leave an entire unprocessed cell uncovered until its completion. Therefore, only the working face at the close of each day's operation was left exposed.

In addition to the Olin Avenue experimental cells, special cells were constructed at other sites for specific studies. These will be described and discussed later. After the Olin Avenue cells had been completed in September 1968, milled refuse was landfilled in a specified area at the

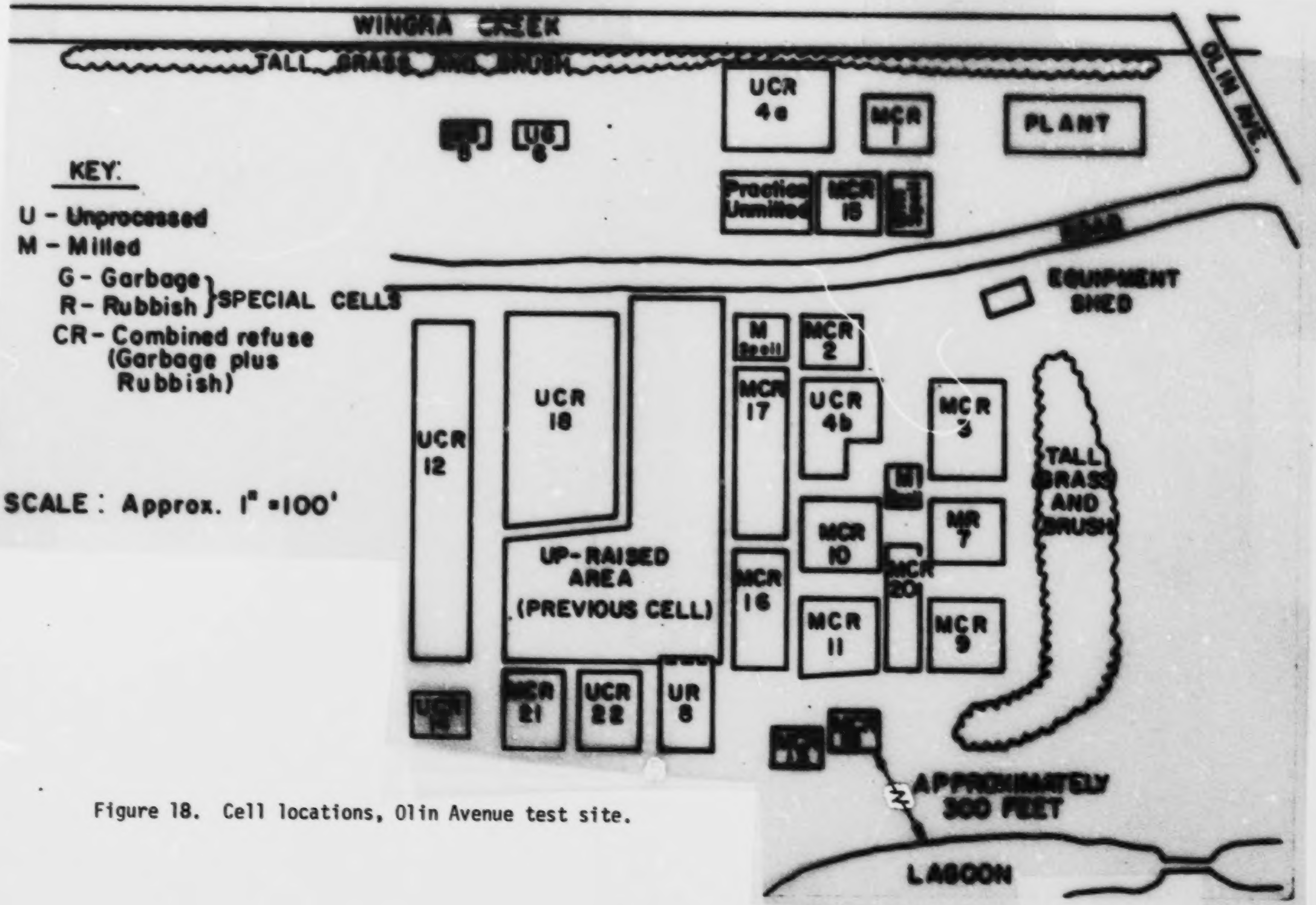
WINGRA CREEK
TALL GRASS AND BRUSH
OLIN AVE.
UCR 4a
MCR 1
PLANT
Practice Unmilled
MCR 15
UG 6
ROAD
EQUIPMENT SHED
M Spall
MCR 2
MCR 17
UCR 4b
MCR 3
M Spall
MR 7
MCR 10
MCR 20
MCR 16
MCR 11
MCR 9
TALL GRASS AND BRUSH
UCR 12
UCR 18
UP-RAISED AREA (PREVIOUS CELL)
MCR 21
UCR 22
UR 8
APPROXIMATELY 300 FEET
LAGOON
KEY:
U - Unprocessed
M - Milled
G - Garbage
R - Rubbish
SPECIAL CELLS
CR - Combined refuse (Garbage plus Rubbish)
SCALE: Approx. 1" = 100'

Figure 18. Cell locations, Olin Avenue test site.

Figure 19. Test cells of milled and unprocessed refuse at Olin Avenue landfill.

TABLE 9

SUMMARY OF TEST CELLS - OLIN AVENUE SITE

Cell No. And Type	Type of Waste Composition	Tons	Grate Size Used in Milling	Period of Construction
MILLED CELLS				
1	Refuse	534	3 1/2	Sept. 18 - Oct. 6, 1967
2	Refuse	450	2	Oct. 9 - 27, 1967
3	Refuse	703	6 1/4	Oct. 30 - Nov. 17, 1967
9	Refuse	474	6 1/4	Dec. 11 - 29, 1967
10	Refuse	689	3 1/2	Jan. 2 - Feb. 1, 1968
11	Refuse	844	6 1/4	Feb. 2 - March 18, 1968
13	Refuse	319	3 1/2	March 18 - 29, 1968
15	Refuse	617	3 1/2	April 1 - 19, 1968
16	Refuse	739	6 1/4	April 22 - May 13, 1968
17	Refuse	733	5	May 13 - 31 ,1968
19	Refuse	499	5	June 3 - 14, 1968
20	Refuse	430	4	July 8 - 20, 1968
21	Refuse	709	6 1/4	July 29 - Aug. 20, 1968
23	Refuse	420	5	Oct. 10 - 22, 1968
5	Garbage	103	6 1/4	Nov. 20 - Dec. 1, 1967
7	Rubbish	310	6 1/4	Nov. 27 - Dec. 8, 1967
UNPROCESSED CELLS				
4A	Refuse	1045		Sept. 18 - Oct. 18, 1967
4B	Refuse	683		Oct. 23 - Nov. 17, 1967
12	Refuse	1456		Jan. 8 - March 15, 1968
14	Refuse	197		March 18 - 29, 1968
18	Refuse	1268		April 1 - May 31, 1968
22	Refuse	548		July 29 - Aug. 20, 1968
6	Garbage	38		Dec. 4 - 8, 1967
8	Rubbish	400		Feb. 12 - March 5, 1968

Olin Avenue site without daily cover. During the entire demonstration period, conventional sanitary landfill operations for unprocessed refuse were carried on at the Olin Avenue site (and at another major city-operated site).

After Christmas 1967, many Christmas trees from Madison's West side were deposited at the project site. To determine if milled refuse could be used as a substitute for cover soil to cover the trees and fill the voids, the trees were bulldozed into as small a pile as possible, and milled refuse was dumped on top of them. A bulldozer then worked the refuse into the voids. The results with milled refuse cover were as satisfactory as with regular cover material. Only minor pockets of settlement occurred after the cover operations with milled refuse.

In another test, during the spring of 1968, milled refuse was used to cover the working face of a pile of unprocessed refuse. This was also concluded to be satisfactory, and resulted in a neat and smooth working face.

The landfill operation with milled refuse quickly provided a test for claims that milled refuse has traffic bearing characteristics superior to unprocessed refuse. In the past, Madison normally had difficult traffic operating conditions in its landfills during spring and fall (Figure 20). The problems were associated with wet conditions during these seasons and with silty-sand cover material used at the landfills. During the demonstration project, however, milled refuse was used to construct access roads to desired dumping areas, and experience showed that a 2-foot depth of milled refuse provides adequate access.

Trucks carrying refuse from the plant to the landfill are now routed over gravel roads built to the milled refuse area and then over the top of the milled refuse pile at the site. Although some trucks weigh nearly 73,000 lbs., they have experienced little difficulty in maneuvering. Tests with both empty and loaded tanker trucks, loaded to and in some cases exceeding legal road limits, also have shown that milled refuse has satisfactory supporting capacity for truck traffic (Figure 21).

Tire damage to equipment at the dumping face of sanitary landfills is common because of large pieces of glass and other sharp objects. Because of the lack of such objects in milled refuse, tire damage has not been a problem for trucks or rubber-tired loaders used on the milled material in the landfill. The only tire damage experienced during this project has been with worn tires on the end loader used in the milling plant.

CHARACTERISTICS OF MILLED REFUSE

The most noticeable feature of milled refuse is its homogeneous character. Milled refuse has the general appearance of oversized confetti. Glass is virtually disintegrated, being ground to particles less the 3/8 in. in size. Many of the cans are completely crumbled.

In early 1972, a magnetic separator was installed in the plant to remove ferrous metals after milling. Currently, this metal, mostly cans, is being hauled by semi-trailer to the Wisconsin Chemical Corporation in Milwaukee where it is de-tinned and then shipped to copper mines in the western United States for use in extraction of copper. This will be discussed in more detail in the section on Trends and Developments.

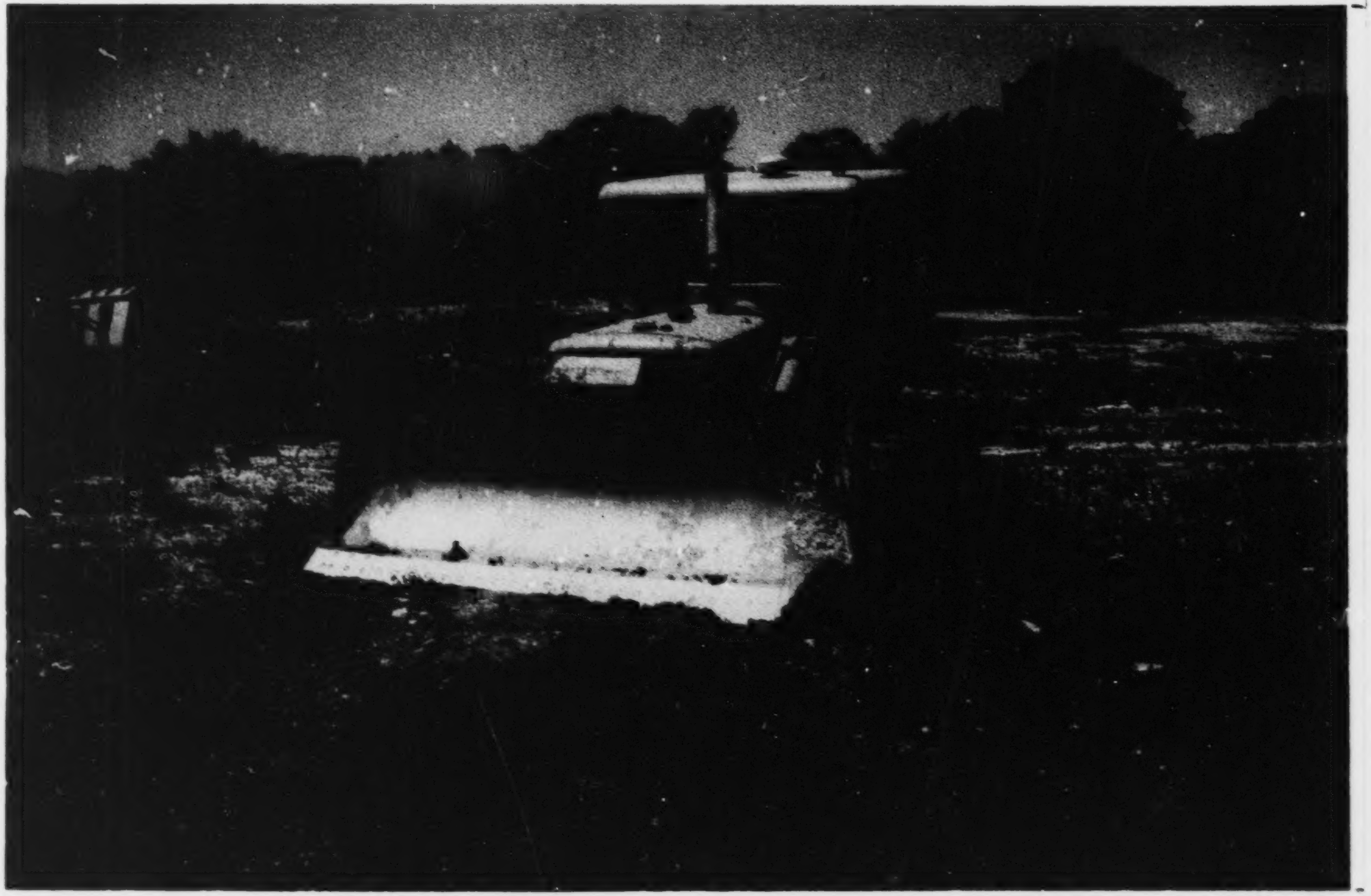

Figure 20. Tracked Dozer experiencing problems operating on silty sand cover material during wet weather.

Blowing and Particle Size

Blowing litter has been one of the major objections to some of Madison's sanitary landfill operations for unprocessed refuse. The extent of the problem depends on wind direction and speed as well as exposure of the working face to the wind. For example, unprocessed refuse dumped at one of Madison's other landfills may be caught by the wind and blown over the boundary and site fences. On occasion, special work details have been sent out to pick up litter from the lawns of homes near landfills. In 1969 alone, some $22,000 was spent for manpower to control and pick up blowing paper from city sanitary landfills. Even 15-foot-high movable fences placed downwind from the working face have failed to solve the blowing problem associated with landfilling unprocessed refuse.

As noted earlier in this report, various grate sizes and hammer patterns were used to obtain a particle size which would reduce blowing problems at the landfill. With properly ground milled refuse, the blowing problem was found to be minimal. Madison's Director of Public Works has stated that this feature alone justifies a milled refuse operation.

Landfilling has been carried out with milled refuse during winds up to 60 mph on a flat site with only minor problems. Those blowing problems that are experienced are usually due to sheets of plastic, which are not thoroughly shredded in the mill and therefore tend to roll across the fill surface. Such items do not become airborne, and are readily caught by low fences (Figure 22).

Three factors may be given to explain the lack of blowing of milled refuse. First, particles of milled refuse tend to become entangled in each other so that they are discharged in clumps rather than as individual particles which can be blown away. Second, the small surface area of individual particles of milled refuse provide a small target for the wind. This is in contrast to a page of newsprint which, caught in a high wind,

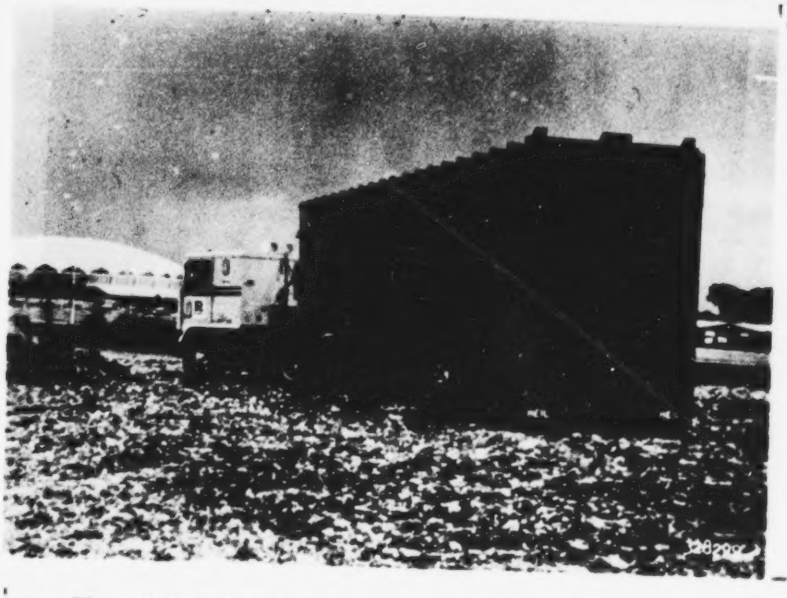

Figure 21. Fully loaded transfer trailer traveling over an 8-foot lift of milled refuse.

Figure 22. Wind-blown film plastic from milled refuse landfill.

acts like a sail and blows for long distances. Observations at the landfill site have confirmed that bits of freshly milled refuse blow only a few feet before coming to a rest. Finally, in a landfill, a crust similar to papier mache forms at the surface of the exposed milled refuse in a few weeks.

A study completed in 1972 was designed to analyze the particle size of milled refuse produced by both the Gondard and Tollemache mills (Figure 23). It was found that the Tollemache mill with a new set of 34 hammers produced nearly the same distribution of particle sizes as the Gondard mill with a 5-in. grate. Between 80 and 90 percent of the particles from both mills passed through a 2-in. screen, and 15 to 30 percent passed through a 0.2-in. screen. All figures are on a dry-weight basis. Particles larger than 1 inch were mostly paper, rags, and plastics, while particles between 0.2 and 1 inch were largely paper, rock, glass, wood, garden trimmings, leaves, and metal pieces. Particles smaller than 0.2 inch were finely ground glass, sand, and ash. Typical particle size distributions for the milled product when both mills are in operation are shown in Figure 23. The variations in grind are due to changing refuse composition, moisture content, and hammer wear.

During this investigation it was found that increased moisture content of refuse results in a more finely ground product, while an increasing degree of hammer wear in the Tollemache mill results in a more coarsely ground product.

Milled refuse appears to be bulkier after it comes out of the mill than in its unprocessed state. It is thought that this is due to "fluffing" of paper and paper products. The fluffing, or bulking, is the reason that the original container system for hauling milled refuse was inadequate for its task (see page 29).

Density

It is important in estimating the life of landfill sites to know whether there is a significant difference in density between milled and unprocessed refuse and whether heavy compaction equipment can produce the same or higher densities as achieved by milling.

Although it is bulkier than unprocessed refuse immediately after milling, milled refuse is reported from European experience to become more dense than similar but unprocessed refuse after it has been compacted in the landfill. To determine relative densities of milled and unprocessed refuse, several field and laboratory tests were conducted in conjunction with the Madison demonstration project.

In 1967 and 1968 field density tests were run at the Olin Avenue landfill. An evaluation of the test results indicated that additional information was required. The major objections to these first tests were: first, the tests did not take into account refuse moisture content; second, due to building the cells above ground in the form of mounds, more cover was required than would ordinarily be used. Finally, the amount of compactive effort was not held constant or controlled during test cell construction.

In 1971 a laboratory testing program was begun to investigate in more detail the density of milled and unprocessed refuse under identical conditions, and to examine the effect of vibration on densities. The test results led to the design of a large-scale field experiment in which as

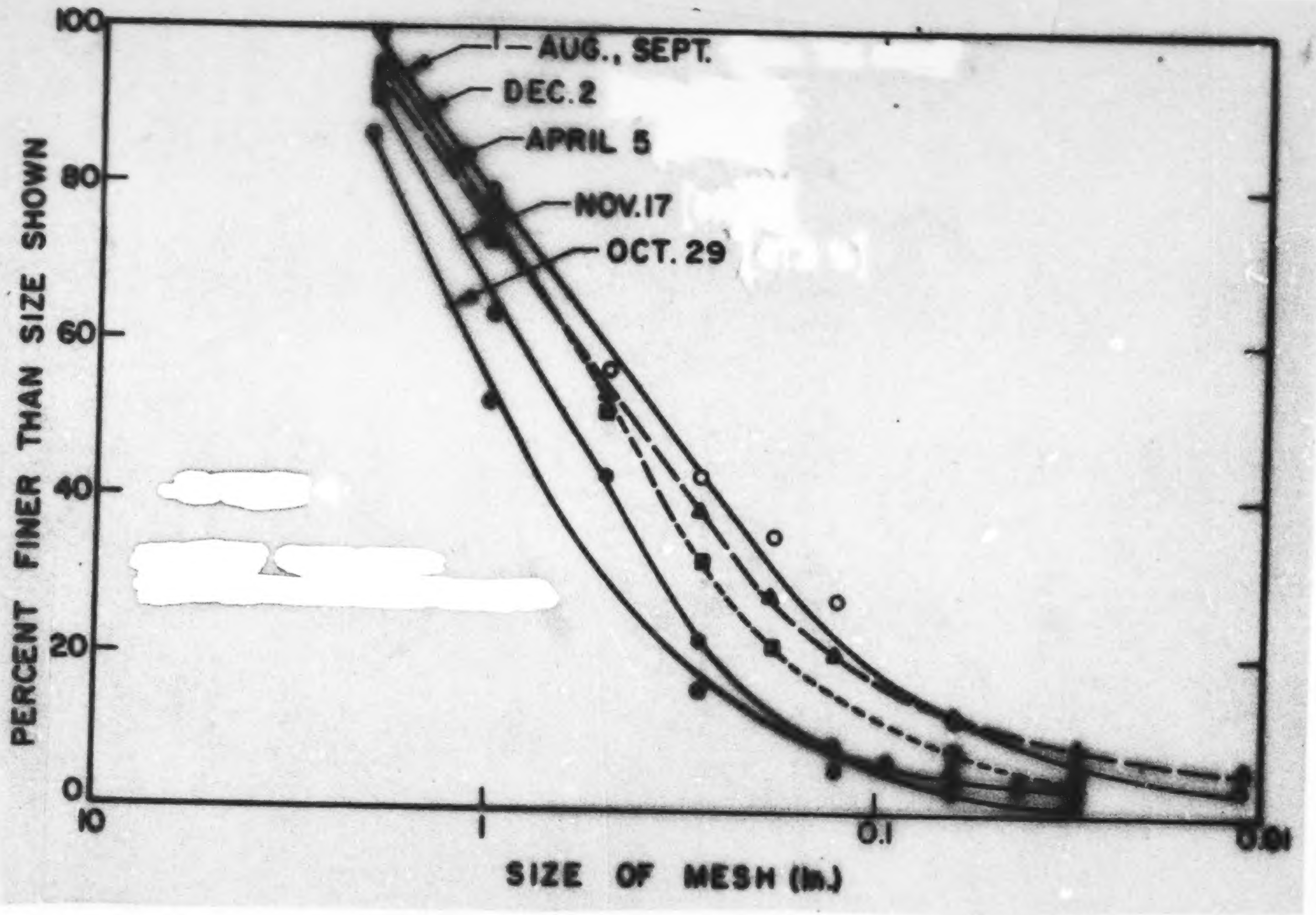

Figure 23. Typical particle size distributions for milled refuse from both mills in 1972.

much control and precision as could be reasonably provided under field conditions was used. This final test on density was run in 1972.

All three testing programs will be described in more detail in the remainder of this section.

Refuse Composition:

Table 10 gives the composition of refuse at Madison as determined by the Bureau of Solid Waste Management in November 1968. While other separation analyses have been run at various times throughout the project, the results have not been found to vary greatly from the composition indicated in the table.

TABLE 10

COMPOSITION OF MADISON'S SOLID WASTE*(November 1968)
(Percent Wet Weight Basis)

Category	Minimum	Maximum	Average
Food Wastes	4.4	28.9	15.3
Garden Wastes	0.0	31.1	13.8
Paper Products	35.1	53.2	42.4
Plastics, Rubber, Leather	0.3	3.7	1.8
Textiles	0.1	7.8	1.6
Wood	0.0	2.6	1.1
Metals	5.0	14.5	6.7
Glass Ceramics	4.4	17.6	10.1
Rock, Ash, etc.	0.6	17.6	7.2

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*Determined by Federal Solid Waste Management Personnel.

Laboratory Study:

To provide detailed laboratory-scale data on densities, comparative tests utilizing both milled and unprocessed refuse were conducted with a compression machine, able to apply loads up to 1,000,000 lbs., in the Engineering Mechanics laboratory of the University of Wisconsin-Madison (Figure 24). To more accurately simulate a landfill compaction operation,

Figure 24. Compression machine with air hammer in place, used to compact milled and unprocessed waste during laboratory investigations.

an air hammer was used to produce vibrations during the laboratory tests. To determine what vibrations were actually produced in the field, a vibration meter was brought to the landfill site and set up near a working D-7 Caterpillar tractor. The vibration pick-up was placed on a steel plate located on the refuse surface approximately 4 feet from the tracks. Results indicated that the tractor transfers vibrations of greater displacement when moving in reverse than when moving forward. The average displacement was found to be 14.02 mils (1 mil = 1/1000 in.), and the frequency was crudely measured at 6 cycles per second. The air hammer was able to simulate these vibrations quite well.

All refuse for the laboratory density test was collected on August 10, 1971. A single truckload of residential solid waste was mixed and 1,000 lbs. were milled with the Tollemache mill; another 1,000 lbs. were removed for testing but left unprocessed. The moisture content was about 45 percent on a dry weight basis. Samples of refuse of each kind were placed separately in a specially built container and compressed under various loads and vibrations. The pressure was increased in increments of 1,000 to 2,000 lbs. (acting over a 4-square-foot area of refuse), and the volume of the refuse was recorded after each increase in pressure. This was continued until there was little or no further compaction. In all cases there was a rapid increase in density to a pressure of about 15 psi. After then, increased pressure resulted in relatively small density increases. The results are shown in Figure 25.

The density of milled refuse was higher than that of unprocessed refuse under all pressures tested. Initially, average actual refuse densities in the containers were 386 lbs. per cu. yd. for milled refuse and 313 lbs. per cu. yd. for unprocessed refuse all on a wet weight basis. Since it was noted earlier that freshly milled refuse is bulkier than unprocessed refuse it is apparent that some compaction of the milled refuse occurred between milling and initial density tests. This compaction is due to the weight of the compression plates in this test and to the tendency of milled refuse to become more dense with time under its own weight. At 5 psi and with no vibrations, the actual refuse density for the milled material was 755 lbs. per cu. yd., while the unprocessed refuse density was 500 lbs. per cu. yd. With medium vibrations (displacement of approximately 20 mils), the actual refuse densities at 5 psi were 828 lbs. per cu. yd. for the milled refuse and 560 lbs. per cu. yd. for the unprocessed refuse, all on a wet weight basis.

The average pressure exerted by a 35,000-lb. D-7 Caterpillar tractor is 7.44 lbs. per sq. in. An extrapolation from these test results at the level of vibration closest to that measured in the landfill indicates that the expected density of refuse compacted with a D-7 in a landfill would be 960 lbs per cu. yd. for milled refuse and 660 lbs. per cu. yd. for unprocessed refuse on a wet weight basis.

Field Tests:

Field determinations of actual and effective refuse densities were conducted which may be compared with the laboratory results. The first field tests were completed in 1967 and 1968 at the Olin Avenue site. All cells, both milled and unprocessed, were compacted in 2 ft. lifts to a 6-foot depth by a D-7 Caterpillar tractor. These tests indicated that milled refuse in a landfill situation has an average actual density of 930 lbs. per cu. yd., while unprocessed refuse has an average actual density of 810 lbs. per cu. yd. and an average effective density of 570 lbs. per cu. yd., all figures

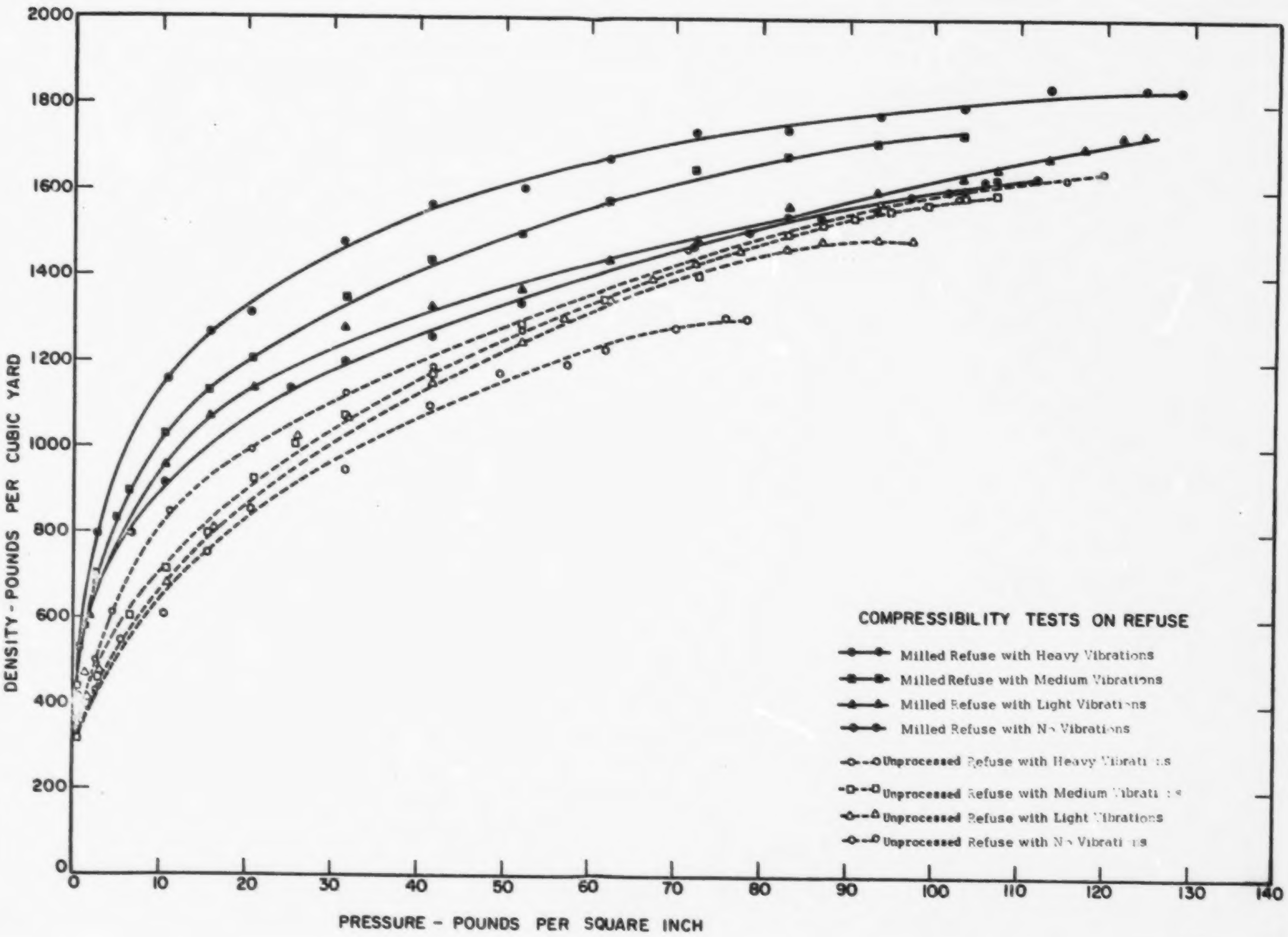

Figure 25. Compressibility Tests on Refuse.

on a wet weight basis. Actual and effective refuse densities are defined in formula form in Table 11; for the purpose of comparing landfill space savings, the effective refuse density figures are more meaningful because they include the volume of cover material used.

Results of the Olin Avenue field density tests were in question, however, because of the lack of control over such aspects as compaction time, cover material usage, moisture content of the refuse, and size of the cells used for comparison. Therefore, new tests were designed to compare the in-place densities of milled and unprocessed refuse placed with equal compactive effort and to compare in-place densities of milled and unprocessed refuse placed under "adequate" compaction as interpreted by an experienced sanitary landfill machine operator. Three 2,000-cu. yd. cells were excavated adjacent to the city's Truax landfill in 1972 (Figure 26). One cell was filled with approximately 1,000 tons of unprocessed refuse, the other two with a similar weight each of milled refuse (Figure 27). The composition of refuse used in this test was typical of Madison's refuse as determined by the separation studies described in Table 10. Refuse used in filling the cells was collected by city packer crews on normal working runs over the entire city. No bulky items were included. The cells were filled in July and August, months during which little change in refuse composition is normally experienced in the city. Moisture content of the refuse varied between 37 and 59 percent on a dry weight basis. A final cover of soil was placed on the cells once they had been filled. The operator was instructed to place only as much cover material as would be used under ordinary landfill conditions.

The refuse for the cells was spread in thin layers and compacted with steel-wheeled 950B Caterpillars weighing 30,000 lbs. to simulate a well-compacted landfill (Figure 28). One of the milled cells was compacted for the same amount of time as the unprocessed cell, or a total of about 24 hours for each cell. A comparison of the postcompaction densities of these two cells shows that the actual refuse density of the milled cell was 1,425 lbs. per cu. yd. while the actual refuse density of the unprocessed cell was 1,119 lbs. per cu. yd., both on a wet weight basis. The third cell, also composed of milled refuse, had an actual refuse density of 1,278 lbs. per cu. yd. on a wet weight basis after it had been given minimal but "adequate" compaction, amounting to about 60 percent of the time spent compacting the unprocessed cell (Table 12).

Results of the field tests tend to confirm the laboratory estimates that, with equal compaction, milled refuse achieves a significantly higher density than unprocessed refuse. While the actual densities obtained in these tests may not have wide application, the relative figures do merit careful consideration. Thus, with equal compaction effort, milled refuse under field conditions shows a 27 percent greater actual refuse density than unprocessed refuse, on a wet weight basis, and a 15 percent greater actual refuse density on a dry-wet basis. Perhaps of more importance when considering space savings, milled refuse has a 35 percent greater effective density than unprocessed on a wet-weight basis, and a 22 percent greater effective density on a dry-weight basis (Table 13). The reason for this difference in density is most likely the fact that unprocessed refuse more commonly contains voids produced by such things as uncrushed cans or by "bridging". Such voids often do not yield to compaction.

TABLE 11

OLIN AVENUE FIELD DENSITY TESTS (1967-68)

Cell No.	Refuse Volume (cu. yd.)	Cover Volume (cu. yd.)	Refuse Weight (wet tons)	Actual* Refuse Density (lb./cu. yd.)	Effective** Refuse Density (lb./cu. yd.)
MILLED CELLS					
1	1120	-	534	950	950
3	1500	-	703	940	940
9	1090	-	474	870	870
10	1820	-	689	760	760
11	2090	-	844	810	810
15	1370	-	617	900	900
17	1340	-	733	1090	1090
21	1250	-	709	1130	1130
			AVE.	930	930
UNPROCESSED CELLS					
4A	3010	670	1045	700	570
4B	1440	550	683	950	690
12	4390	2190	1456	660	440
18	2865	1455	1268	880	590
22	1245	635	548	880	570
			AVE.	810	570

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* Actual Refuse Density = Wt. Refuse/Vol. Refuse

** Effective Refuse Density = Wt. Refuse/(Vol. Refuse + Vol. Cover)

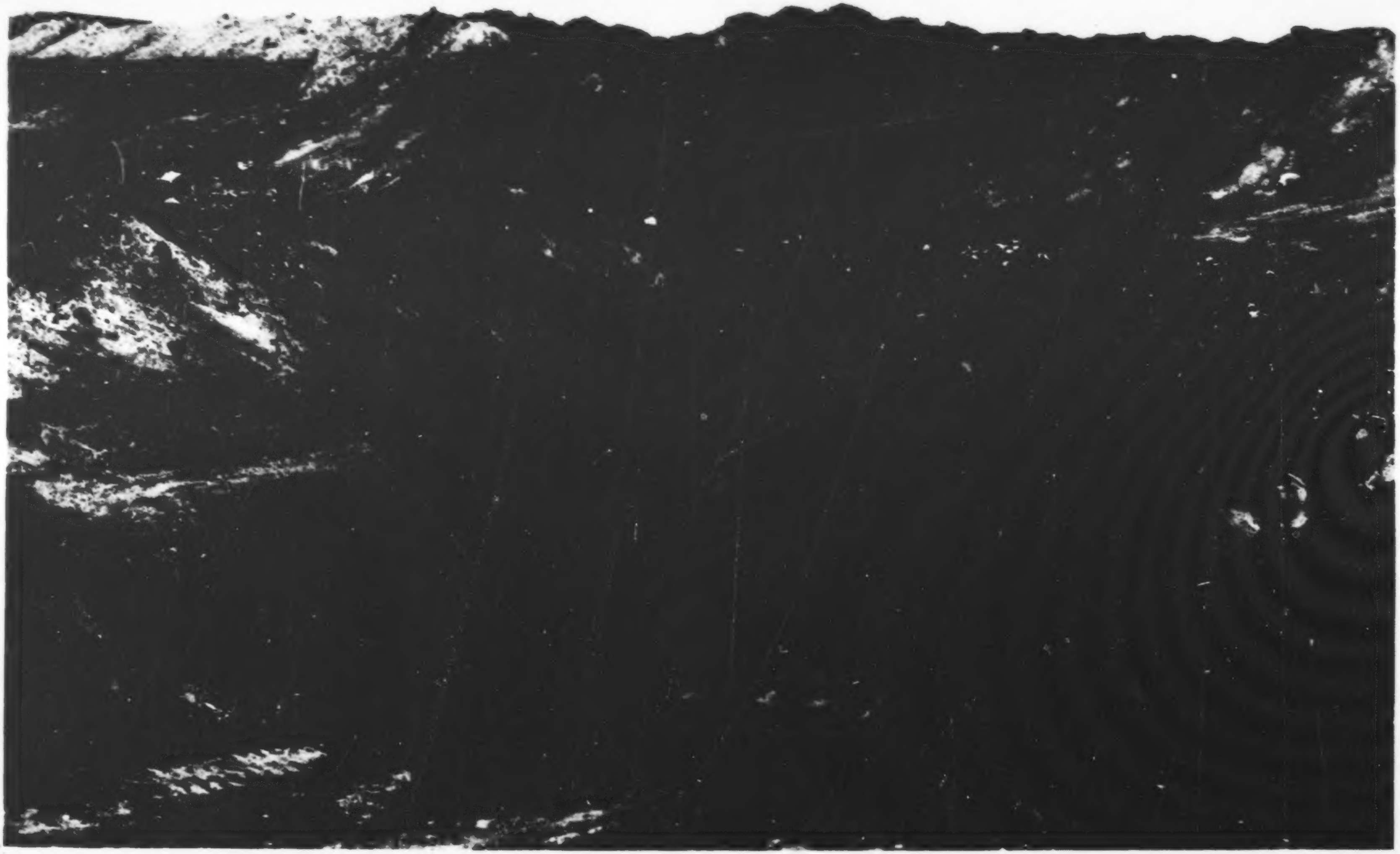


Figure 26. One of three 2000-cu-yd. cells constructed at Truax Landfill to conduct field density tests for milled and unprocessed wastes.

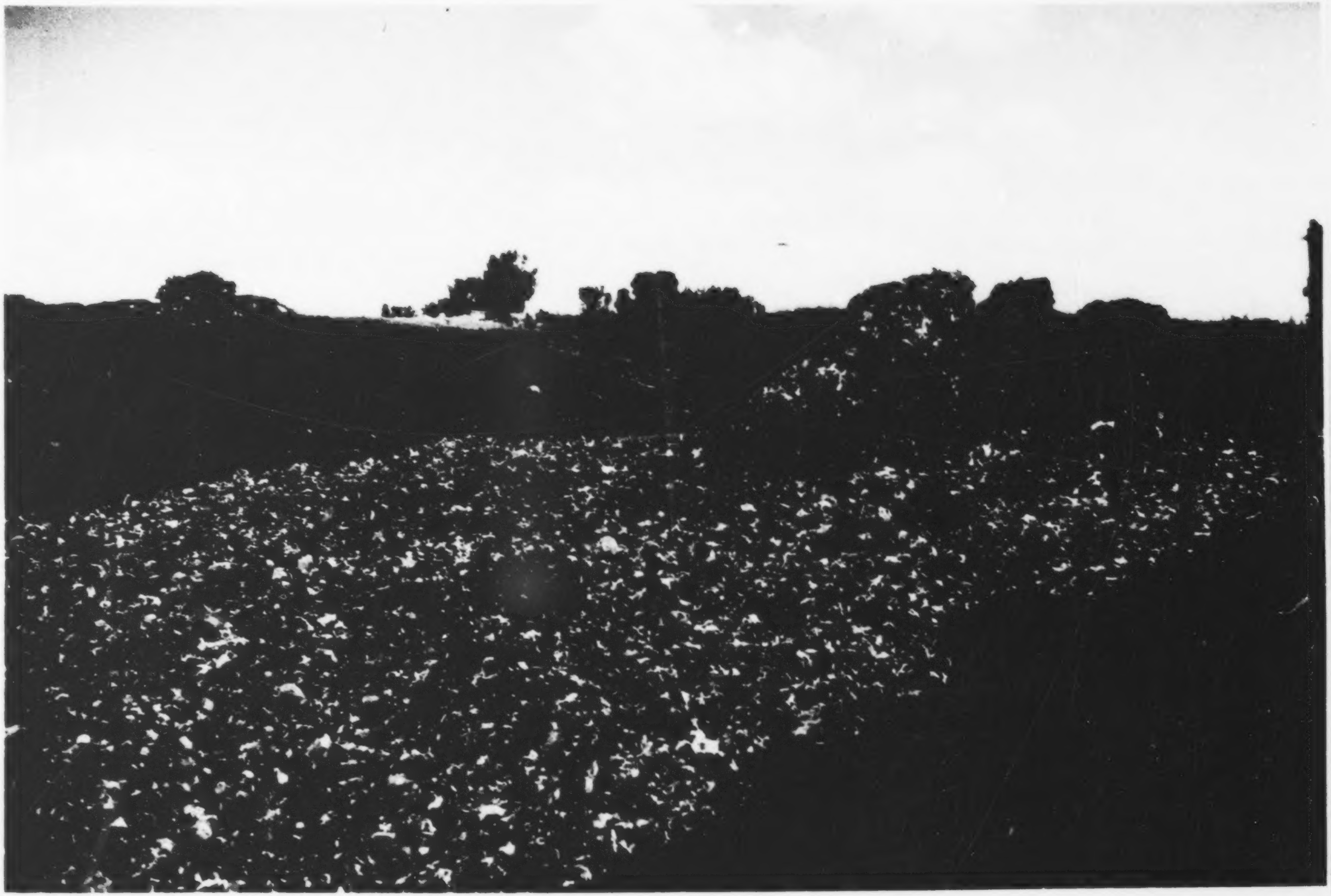


Figure 27. Pit filled with milled refuse for density tests.

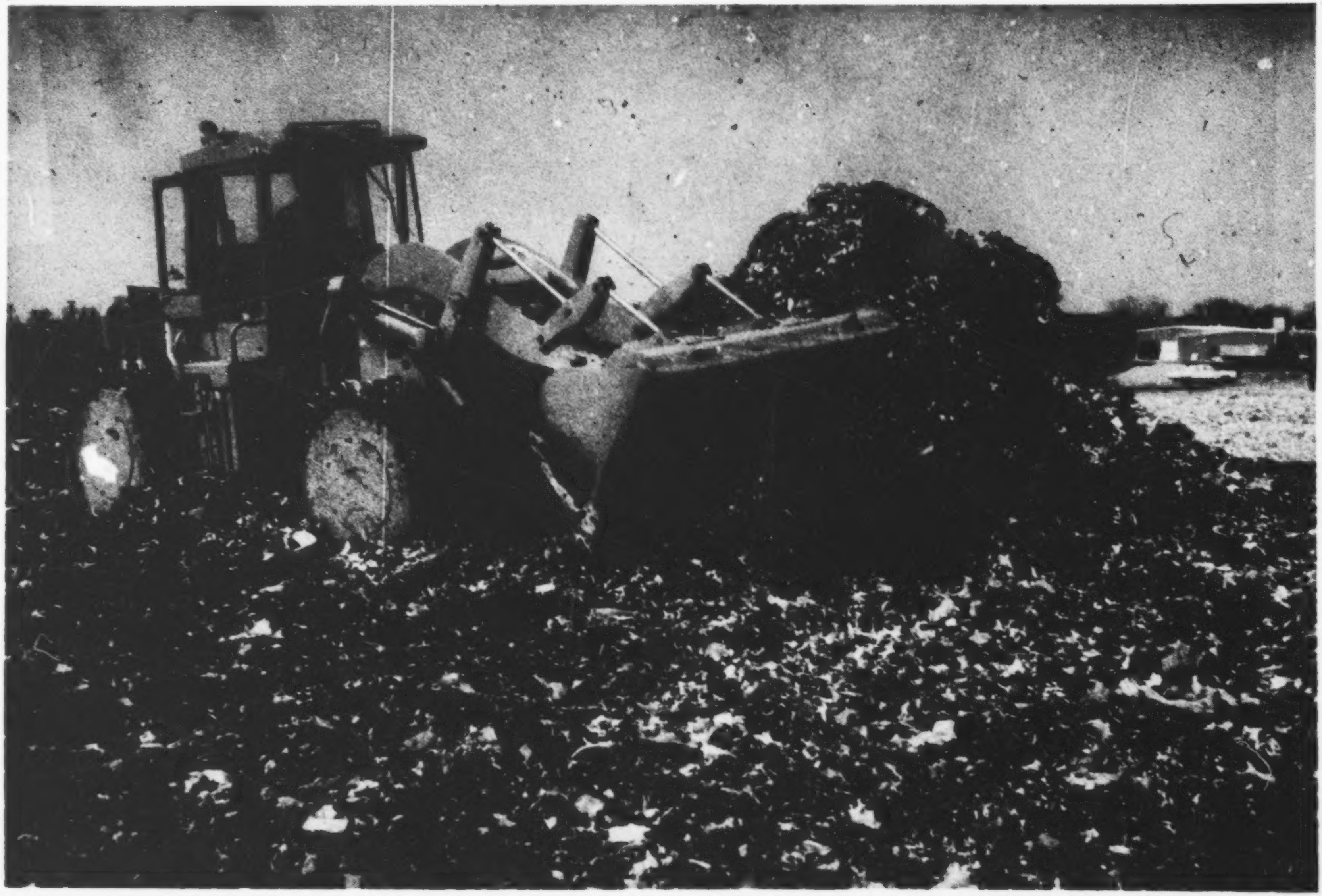


Figure 28. Pushing milled refuse with a steel-wheeled compactor.

TABLE 12

RESULTS OF TRUAX FIELD DENSITY TESTS (1972)

Cell No.	Type	Compaction Time (Hrs.)	Refuse Volume (cu. yd.)	Cover Volume (cu. yd.)	Total Volume*	Refuse Weight (wet tons)	Refuse Weight (dry tons)	Actual** Refuse Density (lb./cu. yd.) WET	Actual** Refuse Density (lb./cu. yd.) DRY	Effective** Refuse Density (lb./cu. yd.) WET	Effective** Refuse Density (lb./cu. yd.) DRY
1	Unprocessed	24.5	1992	286	2224	1114	806	1119	810	1000	724
2	Milled	23.7	1598	130	1689	1139	745	1425	934	1349	883
3	Milled	14.1	1938	154	2023	1236	779	1278	804	1210	768

* Total volume does not equal the sum of the refuse volume and cover volume because the in-place refuse was further compacted and sifting of cover into the refuse as cover material was applied and compacted.

**Detailed in Table 11.

TABLE 13

PERCENT INCREASE OR DECREASE OF DENSITIES OBTAINED IN TRUAX FIELD DENSITY TESTS* (1972)

Cell No.	Type	Compaction Time (Hrs.)	Change In Wet Actual Density	Change In Dry Actual Density	Change In Wet Effective Density	Change In Dry Effective Density
1	Unprocessed	24.5	0	0	0	0
2	Milled	23.7	+27.4	+15.3	+34.9	+22.0
3	Milled	14.1	+14.2	- 0.7	+21.0	+ 6.1

*Cell 1, containing unprocessed waste, used as a base.

Settlement

Plates to measure settlement of milled and unprocessed refuse were installed in the oldest Olin Avenue test cells and the lysimeter beds, but accurate readings over long periods have proven difficult and the results inconclusive. Factors which have made it impossible to draw conclusions from settlement data include changing refuse composition and noncomparable degrees of compaction.

Observations by project personnel have been that milled refuse settles less than unprocessed refuse, undoubtedly due to the higher initial density and less "bridging" of milled refuse. Attempts were made to recompact a milled refuse cell at theOlin Avenue site after 1 1/2 years, but very little additional compaction was achieved. This again indicates the relative stability of milled refuse in a landfill situation.

Observations will be continued on existing refuse cells at Madison in an attempt to make quantitative determinations of settlement of milled and unprocessed refuse.

Decomposition

The top foot or two of a milled refuse cell that has been in a landfill for several months begins to decompose to a brown, mulchlike material, except for stable items such as plastic and glass, which remain intact. The rate and extent of degradation, as well as the rate and extent of removal of matter from milled and unprocessed refuse in a landfill, are dependent on a variety of interrelated factors. The two basic mechanisms resulting in a change of appearance of refuse and in removal of matter from refuse are: 1) physical or chemical leaching and 2) biological decomposition.

Physical and chemical leaching is brought about by the flow of water which rinses matter from the refuse. Biological decomposition refers to the degradation of refuse to leachable matter, gas, or more stable decomposition products by biological activity. These two basic mechanisms are dependent on the following:

1. Presence of water

Water falling on a cell of milled or unprocessed refuse, covered or uncovered, will either run off the surface, evaporate back into the atmosphere, or infiltrate downward into the cell. Water which infiltrates will increase the moisture content of the surface layer until that layer can hold no more moisture. After that, the addition of more water to the top layer will cause some water to flow to the next lower layer. As the process continues, more layers of refuse become saturated (or reach what is defined as field capacity) until the cell can hold no more water. At this point, any additional water added to the cell will displace a like amount of water into the soil or bedrock beneath the cell as leachate. Water flowing through a refuse cell in this manner, plus the water originally landfilled with the refuse, brings about physical and chemical leaching and is a prerequisite for biological activity. The amount of water present in the refuse at the time of landfilling is generally well below field capacity and so will not by itself result in leachate production; however, it does commonly support initial decomposition processes.

It is important to observe that the rate of increase of moisture content to field capacity, and the amount of leachate generated, are functions of the surface characteristics of a refuse cell or landfill. The field capacity of refuse would be expected to be basically the same whether it is unprocessed or milled. Therefore it follows that volume production of leachate is dependent more on the surface characteristics of the landfill than whether or not the refuse is processed.

While it is possible to increase runoff from a refuse cell by using clay and silt cover material and by controlling slope to avoid ponding, it is almost impossible in humid climates to prevent infiltration short of employing artificial barriers such as plastic sheeting. With milled refuse left uncovered, therefore, it may be predicted that there will be little runoff and considerable infiltration. It may also be predicted that the presence of paper particles on the surface of such a cell will act to promote evaporation, offsetting in part the increased infiltration and reducing the amount of leachate.

2. Temperature

The greater the temperature within a refuse cell, the more quickly biological activity proceeds. The ambient temperature is important as it modifies the refuse temperature.

3. Presence or absence of air

Aerobic decomposition, which takes place in the presence of air, is the characterized by rapid activity which produces sufficient heat to raise refuse temperature as much as 30° to 40° F above ambient at a depth of 6 feet. If the rate of oxygen use exceeds the rate of replenishment, the refuse cell becomes anaerobic and a new group of organisms predominates. In the first stage of anaerobic decomposition, organisms which can tolerate the presence of some oxygen begin the decomposition of organic matter. Thus, partially decomposed organic matter is made available to the leachate, resulting in high levels of chemical oxygen demand. Since some of these organics are acidic, pH drops, and some inorganic matter is solubilized.

As decomposition proceeds further, all oxygen is depleted and methane-forming bacteria predominate. These organisms decompose organic matter more completely to methane and carbon dioxide. At this point the chemical oxygen demand of the leachate decreases and the pH rises. This second stage of anaerobic decomposition is commonly associated with little or no temperature rise.

4. Effect of milling and mixing

Milling is thought to enhance the rate of physical-chemical leaching and biological decomposition by increasing the surface area of the refuse. Also, the mixing produced by milling reduces pockets of relative inactivity that are common in piles of unprocessed refuse. Further, water flows more evenly through the entire volume or refuse if it is milled, rather than flowing through channels as it often does in unprocessed refuse. These factors lead to more uniform and rapid decomposition of milled refuse.

With these basic mechanisms of decomposition in mind, studies were undertaken to determine the effect of decomposing milled refuse on the environment as well as the effect milling has on the rate of stabilization of refuse. Three major studies were conducted -- two under field conditions and one under controlled conditions at the University of Wisconsin-Madison Biotron (a controlled-environment test facility). The results of these studies are discussed in the following two sections.

Leachate

Olin Avenue Tests:

The first set of tests to evaluate the comparative effects of milled and unprocessed refuse with respect to leachate production was performed using the test cells at the Olin Avenue site. These cells were constructed between October 1967 and October 1968. Unprocessed refuse cells were covered with at least 6 inches of soil; the milled refuse cells were not covered. In addition, four special cells were built to represent the extremes in landfill situations. Two of these cells were composed of specially collected garbage -- one unprocessed and covered, the other milled and not covered except for the sides. The other two cells were composed of rubbish -- again, one unprocessed and covered and the other milled and not covered.

Fifteen cells, including the four special cells, were equipped to collect leachate. A plastic sheet was placed under portions of each of these cells. Leachate was channeled into collection reservoirs by proper contouring of the plastic sheets. Leachate was sampled by pumping from the reservoirs. In obtaining a sample, the first 2 liters were discarded, and the sample was obtained from the second 2 liters. The reservoirs were then pumped dry and the total volume noted.

Data obtained in the field included the amount of leachate pumped (in milliliters) and the temperature of the leachate (in degrees centigrade).

Leachate commonly contains a wide variety of contaminants and other substances, often in large concentrations. It was decided to categorize the most important substances and to determine their presence as a group wherever possible. Certain other parameters were analyzed because of their individual importance. These other parameters included chlorides, total and calcium hardness, alkalinity, iron, nitrogen, phosphates, and pH.

The two basic analyses performed on the leachate, however, were chemical oxygen demand (COD) and specific conductance. COD is a widely used evaluation of the amount of oxygen needed to oxidize chemically the matter in a water sample. As used in these studies, the COD test results were primarily related to the amount of organic matter in the leachate, although inorganics can add to the COD in anaerobic waters. Biological oxygen demand (BOD) was not measured because of problems of precision at the very high dilutions required, because BOD is not as good a measure of organic content as is COD, and because of reservations about the usefulness of BOD results in the leachate system.

Specific conductance, also called conductance, is a gross indicator of the total concentration of dissolved inorganic matter, or ions. Thus, conductivity and COD roughly measure the inorganic and organic content, respectively, of a water sample reasonably free of particulate matter.

The presence of particulates was observed to vary widely depending on how a sample was taken. For example, the exact location of the sampling hose markedly influenced the amount of sediment or particulates pumped out. Thus, all samples were allowed to settle for 4 hours before the supernatant was drawn for analysis. This procedure minimized the effect of changes in particulates resulting from sampling. The settled sample probably represents more closely the quality of leachate leaving a landfill site since undoubtedly only the finest particulates are not removed from leachate during passage through the first layer of soil.

The Olin Avenue cells differed in size, thus making comparisons of leachate data from the various cells difficult. Different amounts of leachate were collected from cell to cell, and the actual amount collected from a single cell may not have been representative of that cell's production. Because of this, neither a determination of the water budget nor a presentation of data in terms of volume of leachate per volume or weight of refuse could be made from the Olin Avenue studies. Some of these difficulties were overcome when similar tests were run under more controlled conditions. These studies will be discussed later.

Four covered cells of unprocessed refuse were instrumented for these studies, but only two provided useful information on leachate. Similarly, of seven milled uncovered refuse cells originally intended for the study, results from only two could be used. The remaining cells had leaks in the plastic sheet, were damaged during subsequent landfill operations, etc. Figure 29 summarizes the leachate production for the four useful cells. For reasons discussed previously, the rates of leachate production cannot be strictly compared from cell to cell, but the shapes of the curves for each are thought to be significant. The production rates for all four cells seem to have stabilized early in 1969, approximately 1 to 1 1/2 years after placement. The two unprocessed cells produced leachate at about the same rate as did the two milled cells until cell 3 was covered. The rates of production increased in all cases during wet periods of the year and decreased during the winter. The effect of cover is seen in the curve for cell 3, where the rate of production was similar to its sister cell, cell 2, until cover was applied to cell 3, 2 1/2 years after construction. All that time the rate of leachate production dropped in cell 3.

COD concentration curves are shown in Figure 30. With the unprocessed refuse cells, COD concentration was cyclic, with peaks in the summer months and valleys in the winter. Also, COD levels remained fairly high throughout the test period, showing no consistent rise or fall over the 2 years of data. Note that data collection stopped when landfill operations encroached upon and finally covered these two test cells. With the milled refuse cells, the COD concentration began at relatively high values but dropped rapidly, with minor seasonal fluctuations during the period, to consistently low levels. The rise in COD for cell 2 in the summer of 1970 should be discounted, because large amounts of water were applied inadvertently to this cell, rinsing out unusally large amounts of COD over this period. Conductivity levels closely mirrored the COD concentrations in both types of cells.

Figure 31 shows the leachate production from the special garbage and rubbish cells. The garbage cells quickly reached a stable level of leachate production, while it took nearly a year longer for the rubbish cells to produce leachate steadily. Comparing first the milled uncovered cells of each type, the paper fraction is evidently important in promoting evaporation and retarding the downward flow of leachate, because the milled rubbish cell produced considerably less leachate than did the milled garbage cell. The paper content may explain to some extent the differences in production rate for the two special unprocessed covered cells, since

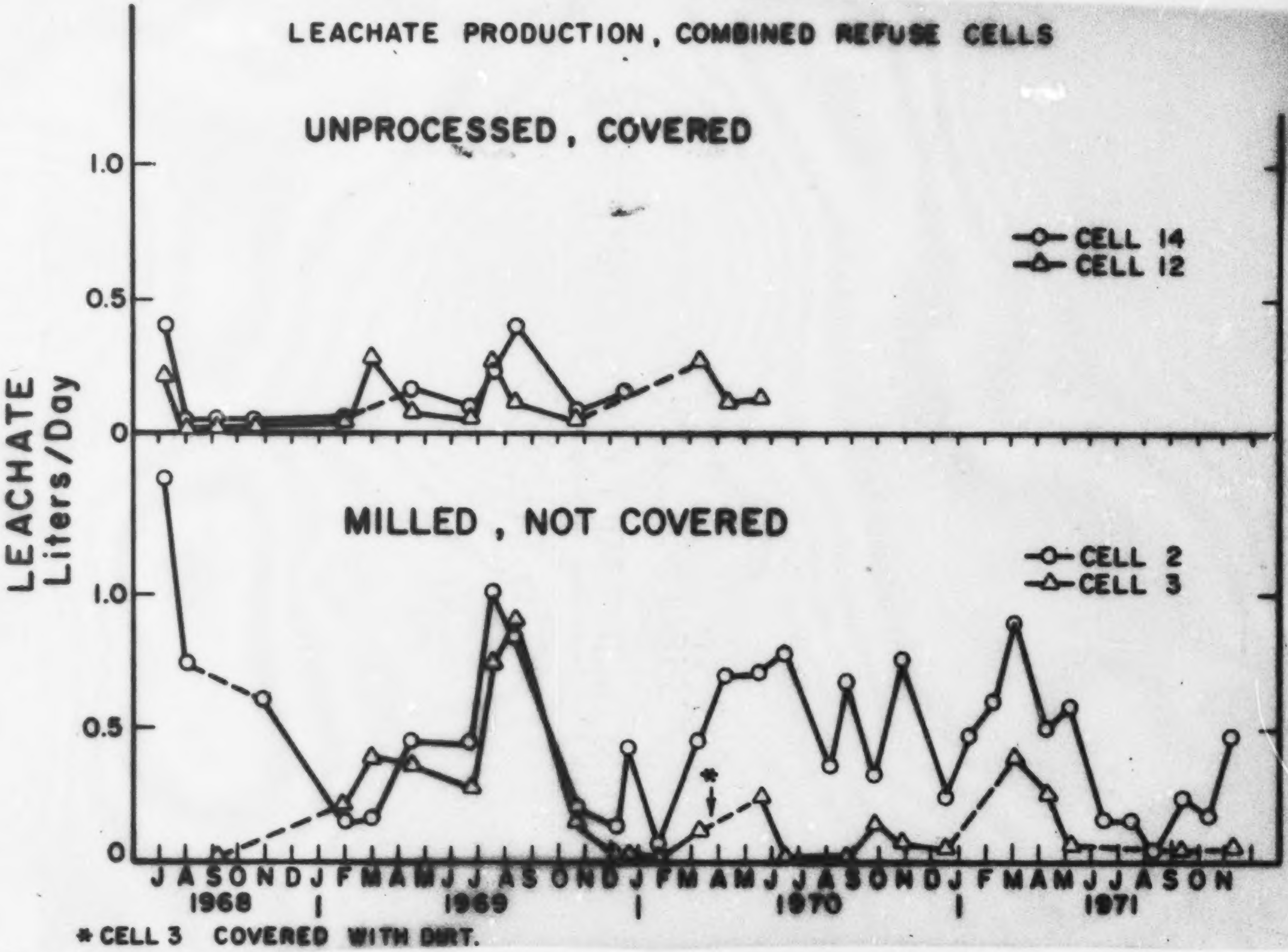
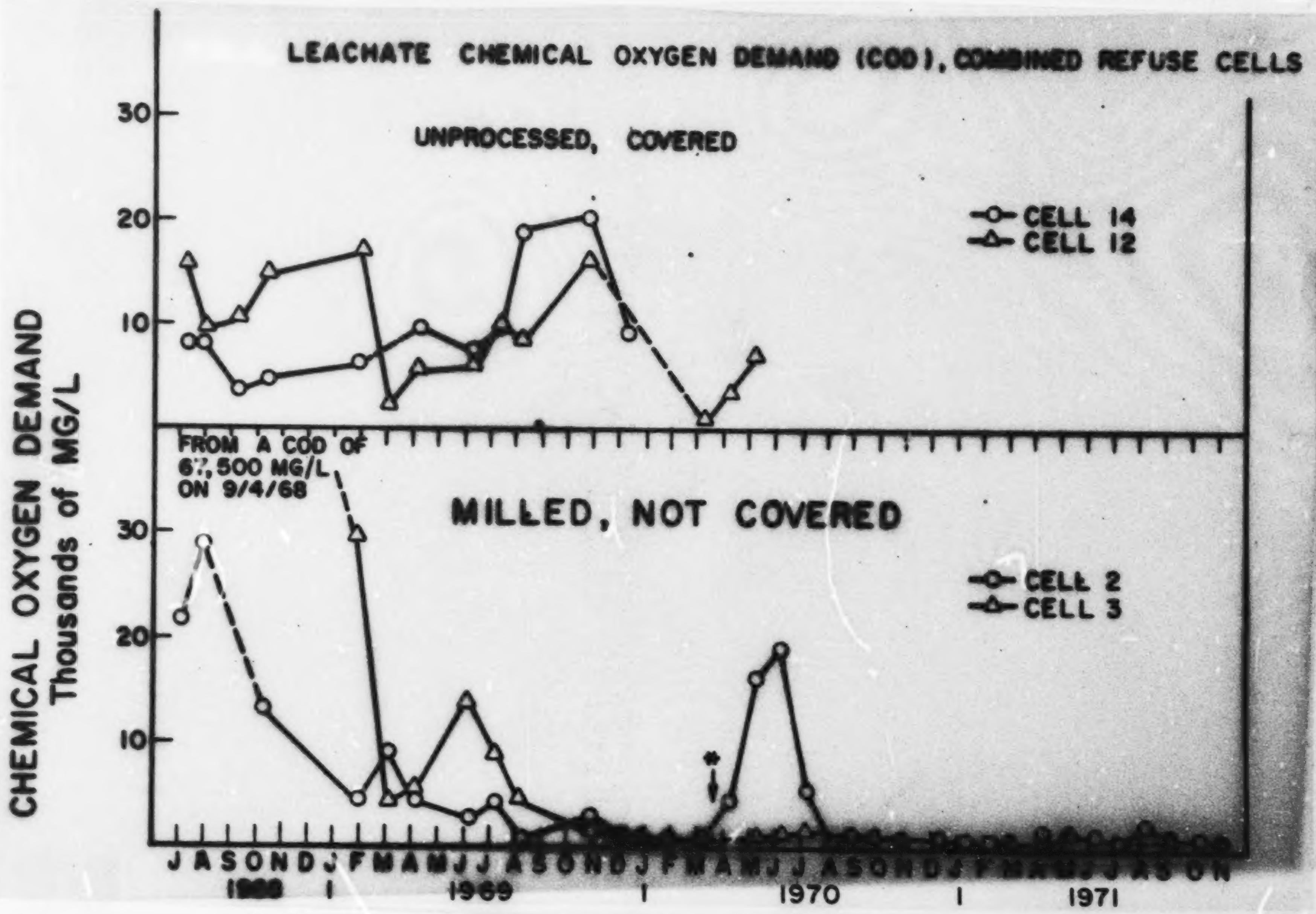


Figure 29. Leachate produced by combined refuse in certain Olin Avenue test Cells.



*Cell 2 received a large dose of water when a nearby fire was extinguished.

Figure 30. Chemical oxygen demand of leachate produced by combined refuse in certain Olin Avenue Test Cells.

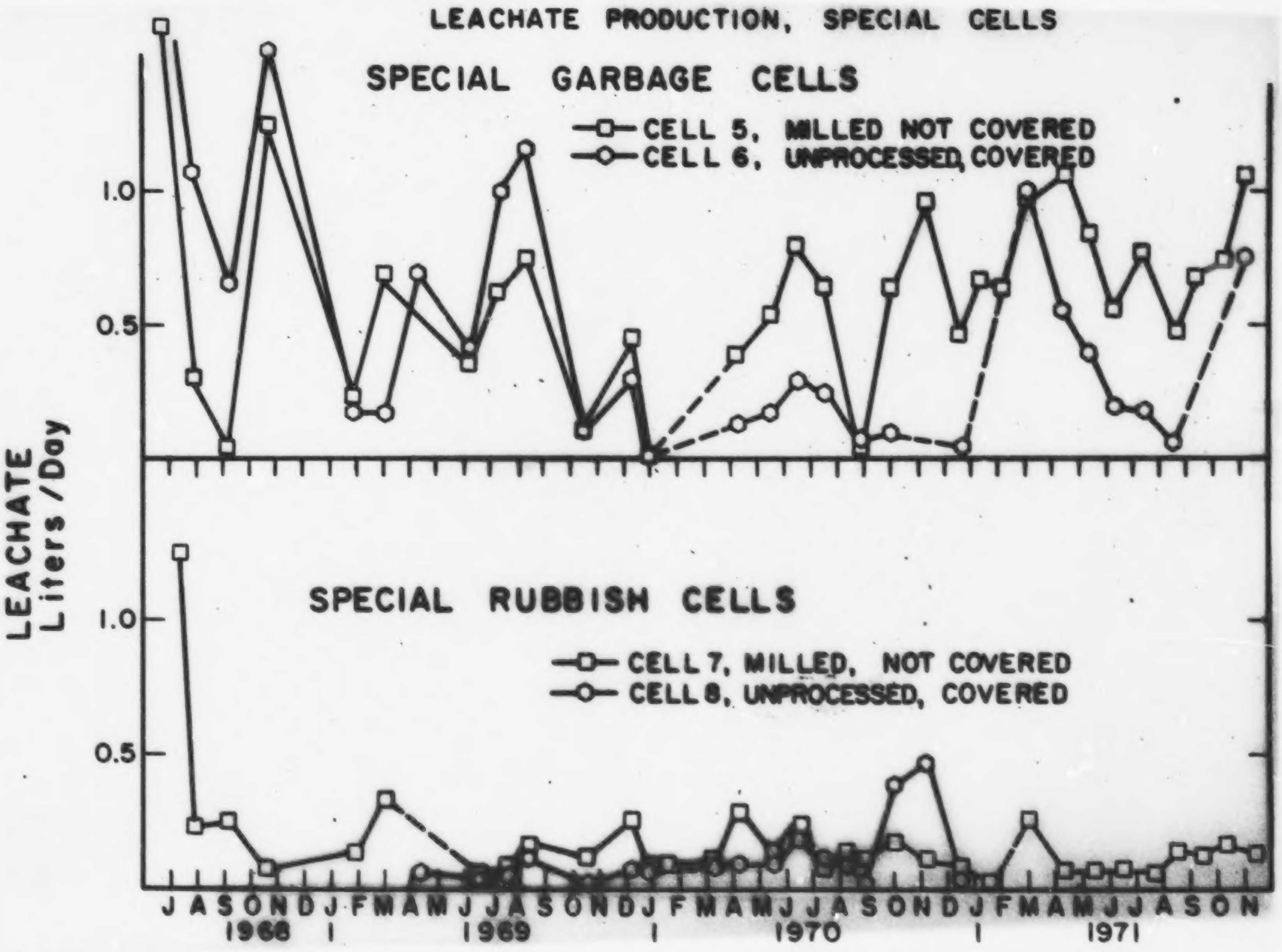


Figure 31. Leachate produced by garbage and rubbish in certain Olin Avenue Test Cells.

paper has the ability to hold moisture closer to the cover-solid waste interface for eventual evaporation. Another explanation, perhaps of some importance, for the difference in leachate production rates among the special cells is the differences (such as size and presence of leaks) in the plastic sheeting underlying the cells.

The COD concentration data from the four special cells are summarized in Figure 32. The garbage cells showed very high COD concentrations compared to the rubbish cells (note the shift in scale). The concentrations for both garbage cells began very high, but rapidly dropped off to low values. In contrast, the rubbish cells produced leachate considerably lower in COD, and did not exhibit as sharp a dropoff in COD concentrations as did the garbage cells. These results are in line with the putrescible character of garbage and with the high paper content of rubbish.

As was the case with the refuse cells discussed earlier, the special garbage and refuse cells show that milling promotes decomposition. Thus, the concentration of COD was stabilized at a low level more quickly in the milled, uncovered cells than in the unprocessed, covered cells. A period of only 1 1/2 years was sufficient to stabilize the milled garbage cell to the point that consistently low COD concentrations were produced in the leachate. In contrast, the milled rubbish cell produced relatively low levels of COD from the beginning. It is doubtful that either the unprocessed garbage cell or the unprocessed rubbish cell has stabilized to any great extent. They were still producing significant COD levels nearly as high as the earlier peak levels in the last summer of testing, and probably would have continued to exhibit summer rises for several years had monitoring continued. Note that data collection on cell 8 was terminated a year early because of the encroachment of landfill operations.

Thus, the Olin Avenue tests strongly suggested that organic material is removed from milled refuse by leachate at a faster rate and over a shorter period than from unprocessed refuse. The unprocessed cells showed more striking rises and falls in organic removal with seasonal changes. While the milled cells generally produced more COD the first year, comparable unprocessed cells produced larger amounts of COD in subsequent years.

Decomposition appears to proceed more rapidly in milled cells, quickly reaching a steady state in which few leachable substances are released. During the initial high period of COD production in milled refuse, a corresponding low pH suggests that aerobic and first-stage anaerobic decomposition is resulting in partially decomposed and leachable organic substances, including organic acids. A few months later, the pH rises to near neutrality and the COD drops, suggesting that anaerobic decomposition is predominant, producing more methane and more completely degrading the organic matter. COD and pH curves for unprocessed cells indicate that these cells did not reach second-stage anaerobic decomposition to any great extent during the period of the Olin Avenue tests.

Conductivity levels showed that inorganics are also removed more quickly from milled than from unprocessed refuse, although the difference is not as pronounced as in the case of COD. Except in the case of the special cells, conductivity and other specific ion curves closely followed the shapes of the related COD concentration curves.

Finally, lechate production rates seemed to be higher for the milled refuse cells than for the unprocessed refuse cells. This difference in leachate production was probably more a function of whether the refuse

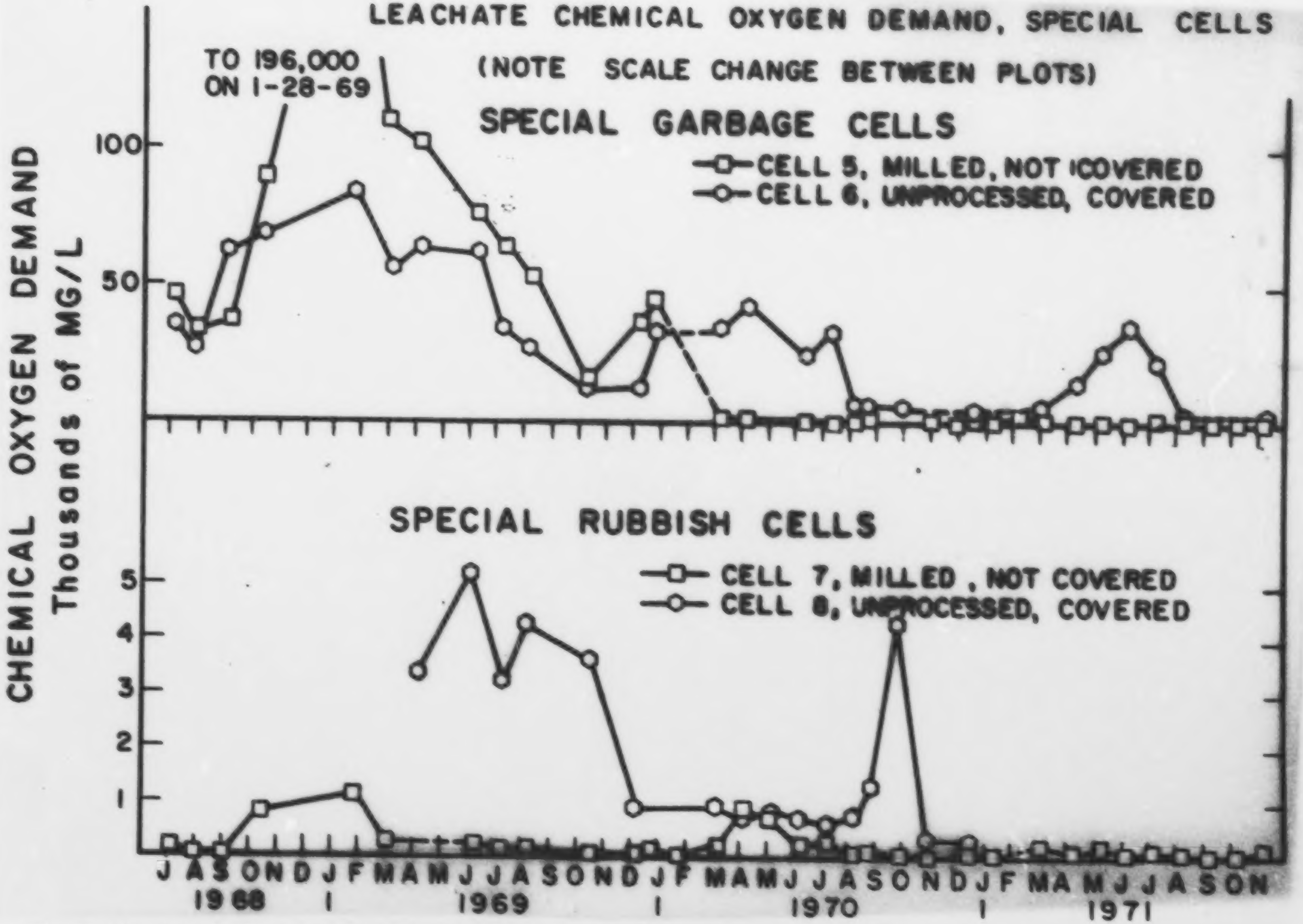


Figure 32. Chemical oxygen demand of leachate produced by garbage and rubbish in special Olin Avenue Test Cells.

was covered rather than whether it was milled. The conclusions on relative leachate production remain tentative, however, because an accurate water balance could not be determined for the Olin Avenue test cells. Subsequent studies were directed in part to provide more accurate water balance information.

Lysimeter Studies:

To overcome some of the limitations imposed by the conditions of the Olin Avenue test, another study was initiated. The object of this project was to isolate various refuse cells from outside influences such as those that limited the usefulness of some of the Olin Avenue cells. A second objective was to obtain a direct comparison of pollutional loads from milled and unprocessed refuse. Third, the effect of cover soil on degradation and pollution loads from refuse was to be determined. Finally, a water budget was to be kept to determine the percentages of precipitation which go to runoff, evaporation, and infiltration (leachate).

Four cells of equal size were constructed in two obsolete sludge drying beds at the Oscar Mayer Company's waste treatment plant in Madison.(Figures 33, 34 and 35). The cells were filled in mid-September 1970 as follows:

#1 unprocessed refuse covered with approximately 6 inches of soil (Figure 36);
#2 milled refuse covered with approximately 6 inches of soil;
#3 milled refuse covered after approximately 6 months;
#4 milled refuse left uncovered (Figure 37).

Each cell contained about 100 tons of residential and light commercial refuse collected within a one-week period. Trucks were routed at random to the various cells to minimize any differences in refuse composition from cell to cell. Approximately 75 tons of silty-sand cover were placed on the cells for which cover was specified. Careful attention was paid to insure that runoff and all leachate were collected (Figure 38). Gas production (discussed in the following section), temperature, and moisture were also monitored.

Data on leachate production are summarized in Figure 39. Production from all of the cells, but from the unprocessed covered cell in particular, varied with the seasons, peaking in spring and fall with the onset of thaws and heavy rains and dropping off in summer and winter. After reaching field capacity, the milled uncovered cell produced leachate at a higher rate than the unprocessed covered cell. Drastic month-to-month fluctuations in leachate production from this cell indicate that leachate production from uncovered milled refuse is more dependent on short term fluctuations in incident rainfall.

The other milled refuse cell that was initially left uncovered produced leachate at a rate consistent with the first uncovered milled cell. However, this cell was covered with 6 inches of material in March 1971, after which it behaved more like the unprocessed covered cell in terms of leachate production. The milled cell which was covered immediately also exhibited leachate production similar to the unprocessed covered cell.

It may be concluded from those data that soil cover has a major impact on leachate production, and this point will be discussed further in later portions of this report.

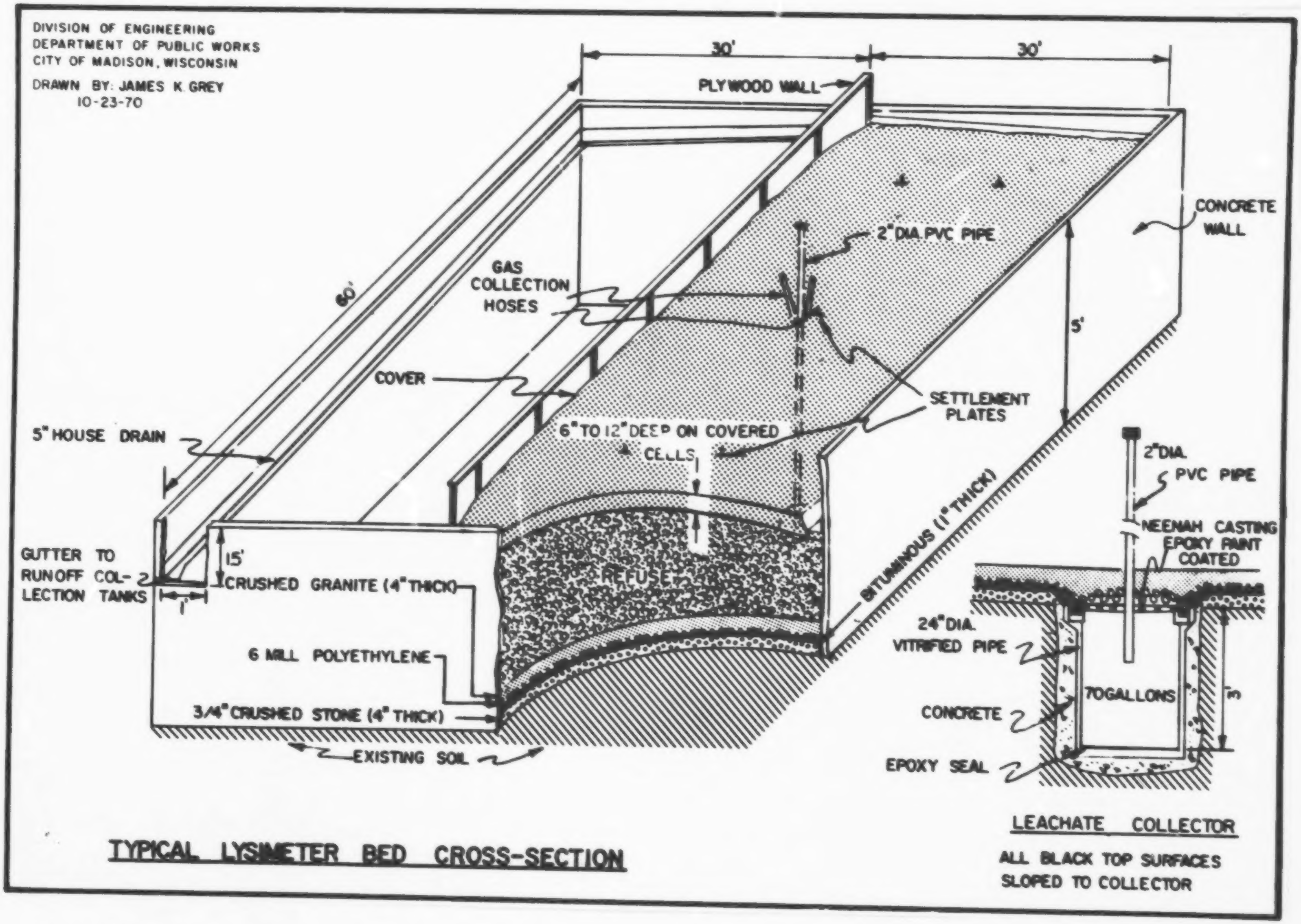

DIVISION OF ENGINEERING
DEPARTMENT OF PUBLIC WORKS
CITY OF MADISON, WISCONSIN
DRAWN BY: JAMES K GREY
10-23-70
30'
30'
PLYWOOD WALL
80'
GAS COLLECTION HOSES
2" DIA. PVC PIPE
CONCRETE WALL
5'
COVER
SETTLEMENT PLATES
5" HOUSE DRAIN
6" TO 12" DEEP ON COVERED CELLS
1'
BITUMINOUS (1" THICK)
GUTTER TO RUNOFF COL-LECTION TANKS
15'
1'
CRUSHED GRANITE (4" THICK)
REFUSE
6 MILL POLYETHYLENE
3/4" CRUSHED STONE (4" THICK)
EXISTING SOIL
2" DIA. PVC PIPE
NEENAH CASTING EPOXY PAINT COATED
24" DIA. VITRIFIED PIPE
70 GALLONS
CONCRETE
EPOXY SEAL
TYPICAL LYSIMETER BED CROSS-SECTION
LEACHATE COLLECTOR
ALL BLACK TOP SURFACES SLOPED TO COLLECTOR

Figure 33. Cross section of lysimeter beds.

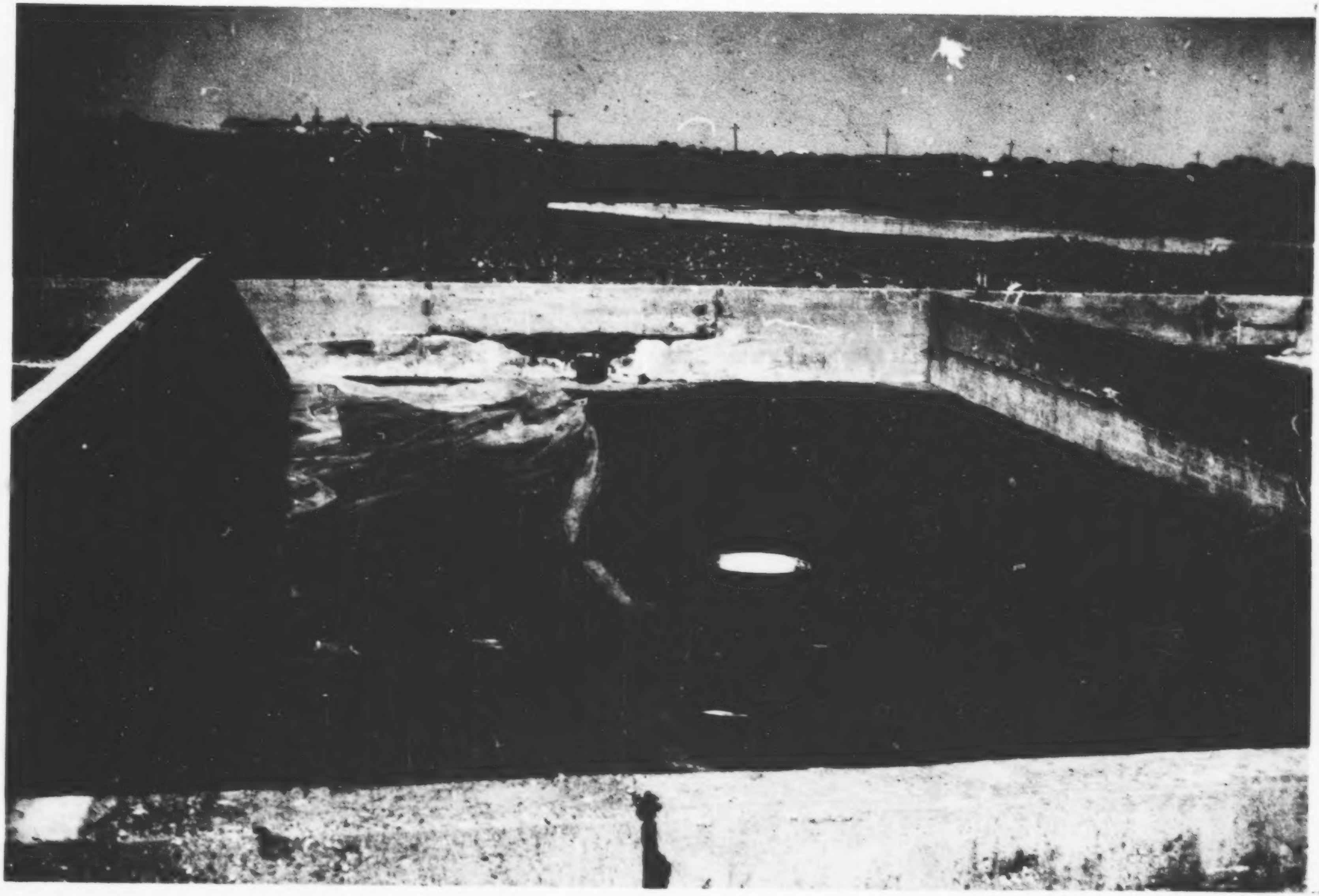


Figure 34. Lysimeter bed prior to receiving refuse.

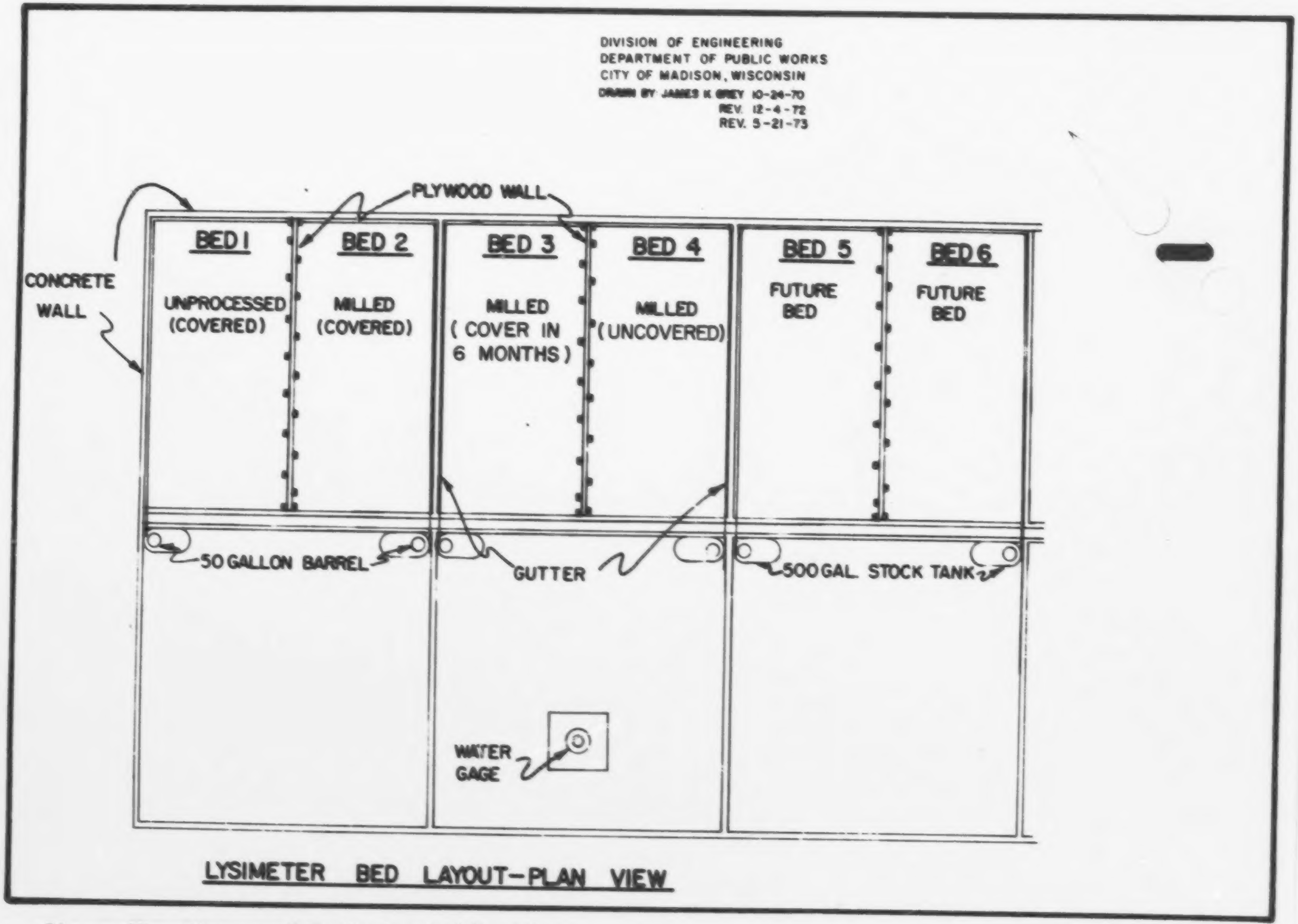

DIVISION OF ENGINEERING
DEPARTMENT OF PUBLIC WORKS
CITY OF MADISON, WISCONSIN
DRAWN BY: JAMES K GREY 10-24-70
REV. 12-4-72
REV. 5-21-73
PLYWOOD WALL
CONCRETE WALL
BED 1
UNPROCESSED (COVERED)
BED 2
MILLED (COVERED)
BED 3
MILLED (COVER IN 6 MONTHS)
BED 4
MILLED (UNCOVERED)
BED 5
FUTURE BED
BED 6
FUTURE BED
50 GALLON BARREL
GUTTER
500 GAL. STOCK TANK
WATER GAGE
LYSIMETER BED LAYOUT-PLAN VIEW

Figure 35. Diagram of lysimeter bed layout.

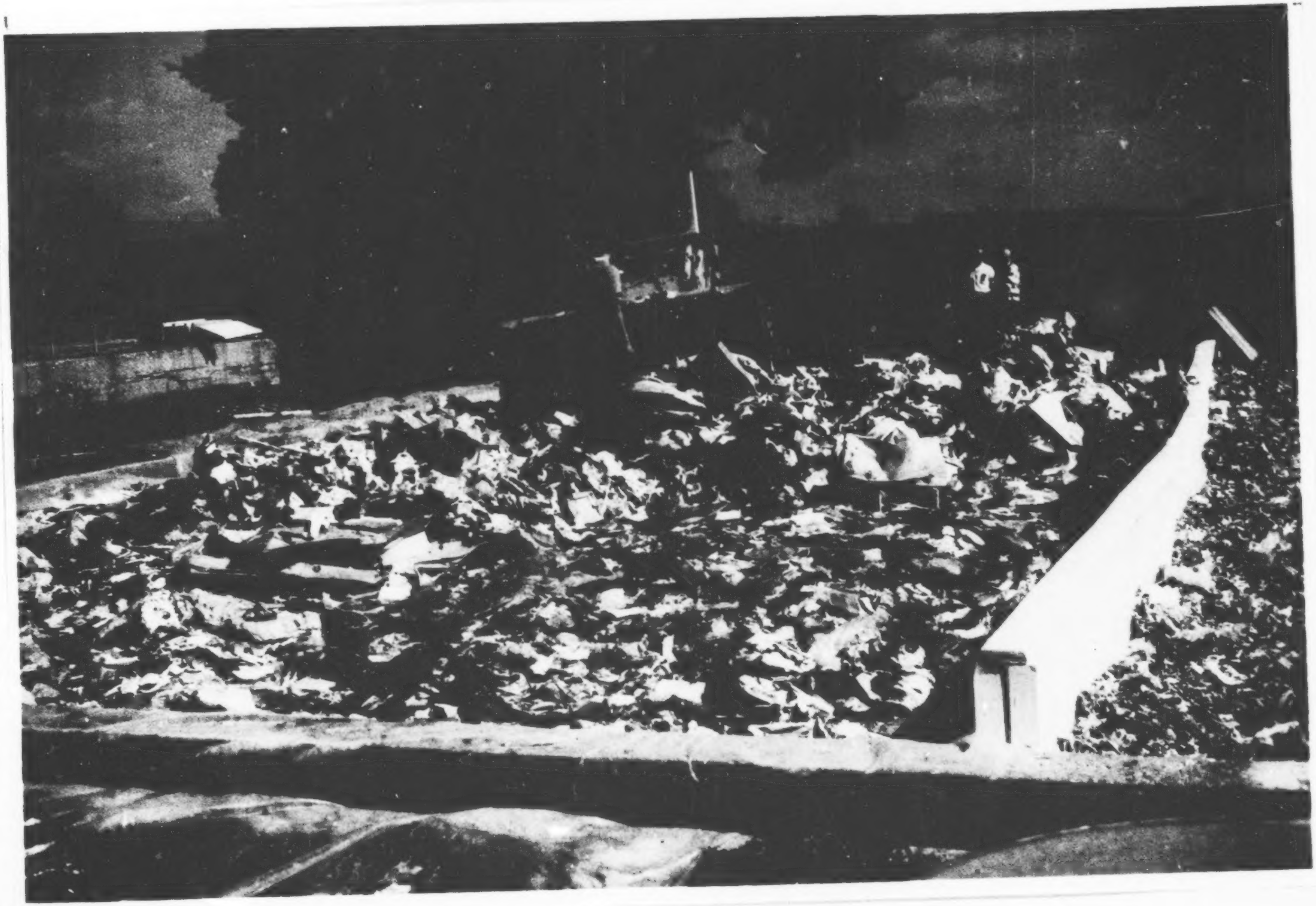


Figure 36. Lysimeter bed being filled with unprocessed refuse.

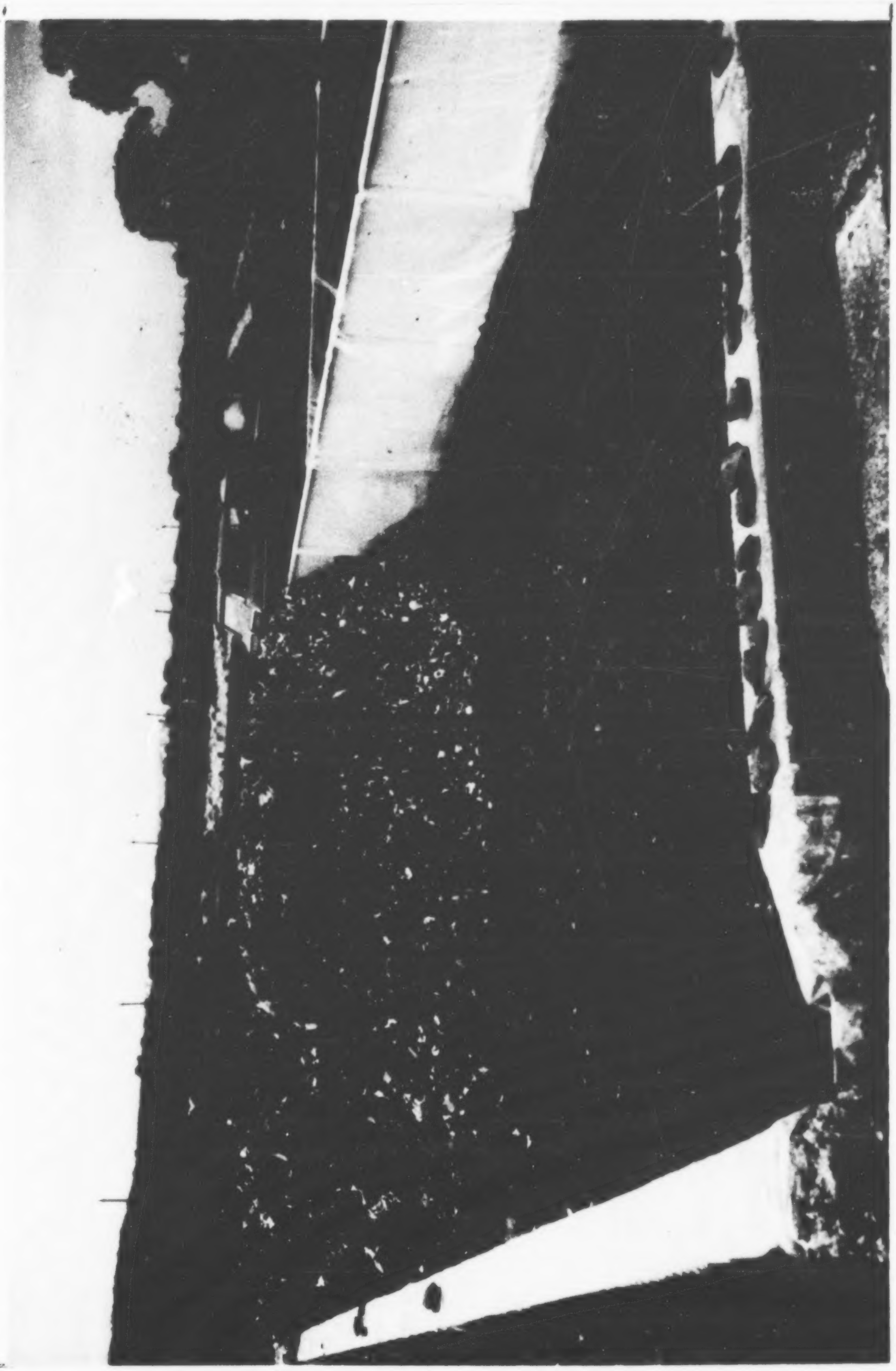


Figure 37. Lysimeter bed being filled with milled refuse.

Figure 38. Cow tanks and barrel arrangement for collecting runoff from test cells.

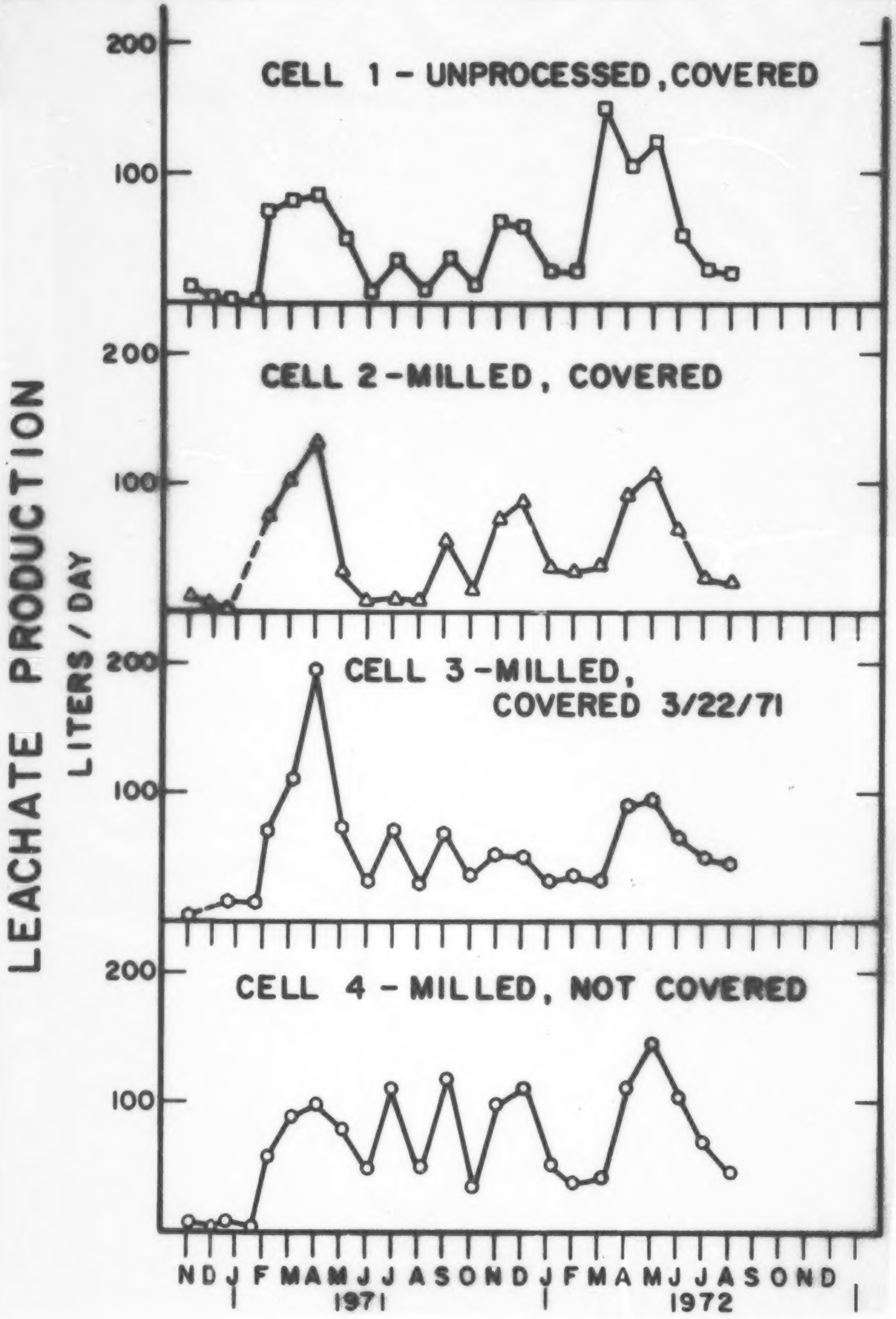


Figure 39. Leachate production from lysimeters.

The COD concentration levels for the cells are shown in Figure 40. Note first that the general shapes of the curves for cells 1 and 4 match very well with the corresponding curves for the Olin Avenue leachate studies. The unprocessed covered cell at the Oscar Mayer site showed a slight initial COD rise, possibly indicating the release of some readily leachable organics. The COD concentration then dropped to lower levels until spring when a large volume of water and rising temperature combined to bring about a substantial removal of organics. Thereafter, the general trend of the curves is slowly downward, interrupted occasionally by especially wet periods.

Data from the Olin Avenue study indicated that the typical milled cell had a high initial peak of COD concentration followed by a decline to low levels, and that a smaller secondary peak usually occurred the following summer. In the lysimeter studies at the Oscar Mayer site, the milled uncovered cell also showed such a curve. The same characteristics were observed in the milled cell which was covered after 6 months, except the initial and secondary COD peaks lasted longer than in the milled uncovered cell. Even more apparent was the heightening and prolonging of the peak levels of COD concentration in the milled cell covered immediately. Again, the presence or absence of soil cover has a pronounced effect on the degradation and pollutant production from milled refuse, an effect which will be analyzed later.

Obviously, COD concentration is not in itself of great importance in its effect on the environment, since a small amount of leachate with a high COD concentration may be no more damaging than a large volume of leachate at a low COD concentration. Thus, to obtain the actual amounts of COD substances produced from a cell, the COD concentration value is multiplied by the average volume of leachate produced per day between samplings. COD production is shown in Figure 41.

Generally, the COD production curve followed the COD concentration curve in the case of the unprocessed covered cell. With all the milled cells, COD production curves rose to a peak very quickly after the cells reached field capacity. The peak for the covered milled cell was not as high as the other two milled cells, but later COD production rates for this cell were higher than for any of the other cells. The excessive peak in April 1971 for the milled cell covered after 6 months was undoubtedly due to a large extent to squeezing of leachate out of the cell by heavy equipment during covering operations in March. This cell and the milled uncovered cell had initial peaks which indicate that COD-producing organics were being removed from these cells quite rapidly.

Note that for the unprocessed covered cell, little trend upward or downward is observable in the COD production curve. In contrast, the general trend of all three milled cells is toward lower COD production with time; the weakest such trend is for the milled cell covered immediately and the strongest for the cell left uncovered. There is a second summer rise for the milled uncovered cell; the second summer rise will probably by very weak or not present in subsequent summers if the Oscar Mayer lysimeter results continue to correspond to the Olin Avenue findings.

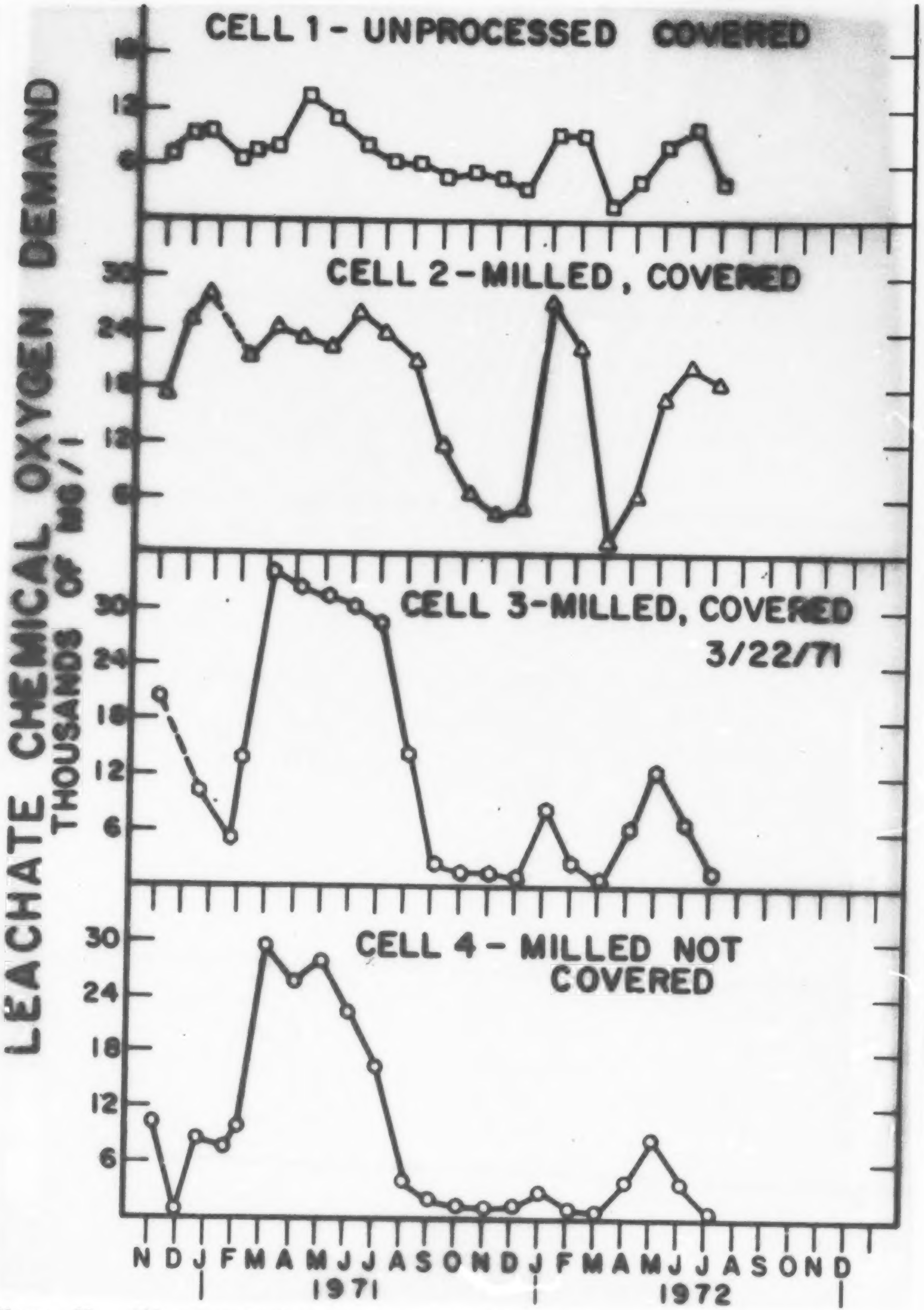


Figure 40. COD concentration curves for lysimeters.

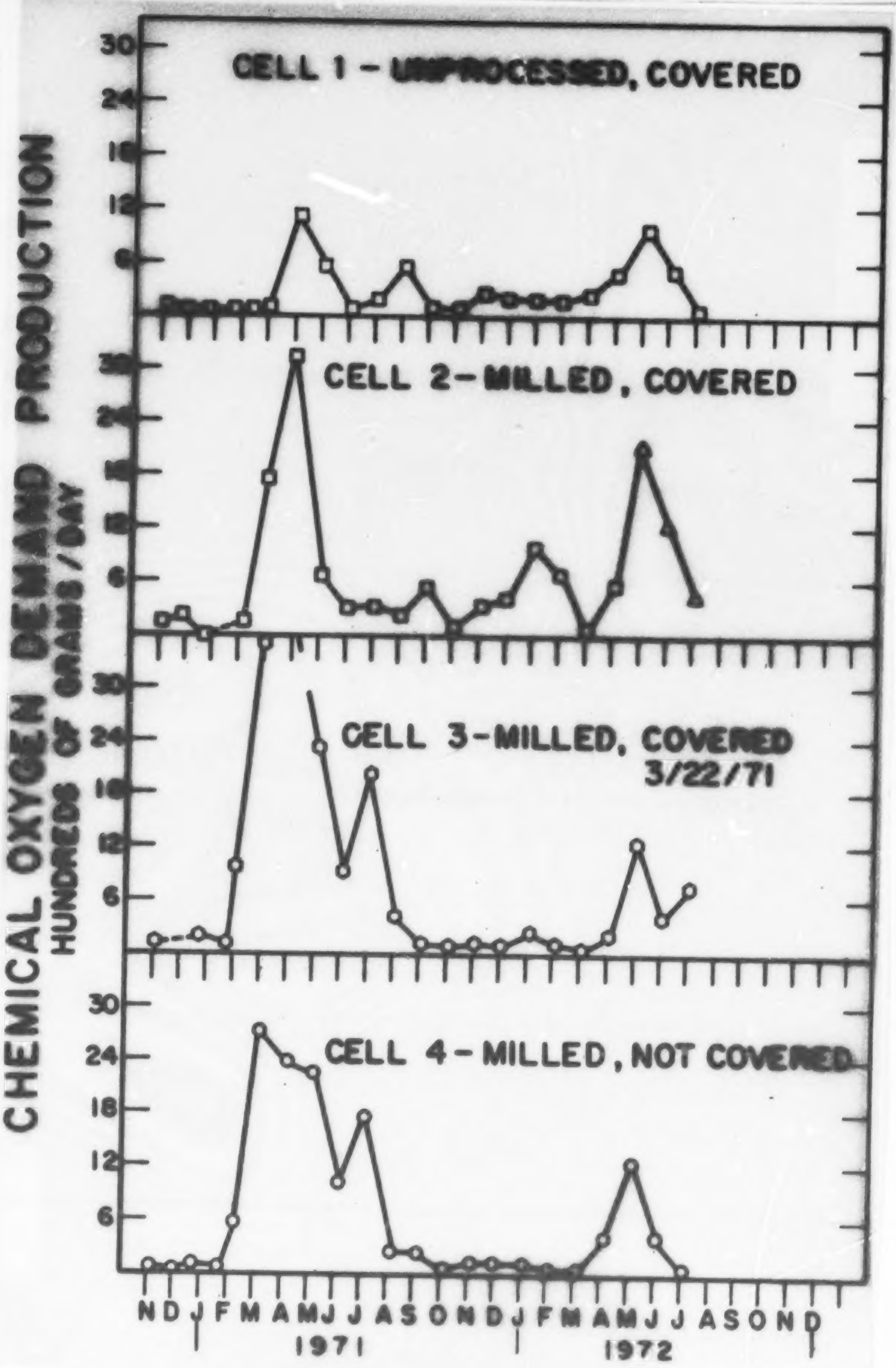


Figure 41. COD production from lysimeters.

The COD production observations can be explained by the nature of milled refuse and the effect of cover. Initially in milled refuse cells without cover, more precipitation infiltrates the refuse and becomes leachate. The finer particles in the milled cell present more surface area to the infiltrating water. Together these two factors result in more grams of COD per day being produced at first in the milled uncovered cells than in the other cells. At the same time, the increased amount of leachate tends to lower the COD concentration. As time goes on, the greater flow of leachate in the uncovered milled cell has less effect on grams of COD produced because the readily degradable and leachable matter has already been removed.

With unprocessed refuse, organic matter particle size is much larger and organic matter is not as well mixed as in the milled cells. In addition, cover material reduces infiltration in the unprocessed cell, with the result that less organic matter is initially leached from this type of cell.

Curves for conductance and specific ions closely followed the COD concentration curves and thus will not be discussed further.

The pH measurement is of interest because it can be used as an indication of what type of degradation process is occurring. Once second-stage anaerobic degradation occurs, the pH should rise to near-neutral levels, the COD production should decrease, and methane should be produced. Acidic pH levels do not promote degradation because of their adverse effects on many microorganisms. Acid pH values are found during the transition between aerobic and anaerobic conditions.

The pH in the unprocessed covered cell has remained acidic throughout the period of this report (Figure 42). This indicates that organic acids are being produced and that organics are not being reduced to their highest state of degradation. Thus, either the refuse itself or the decomposition processes have not reached stable, relatively harmless conditions.

The striking effect of soil cover on the degradation process is observed in the pH data from the milled cells. The covered cell maintained an acidic pH, whereas the other two cells more closely approached neutrality (pH = 7). The leachate from the uncovered milled cell has been less acidic than that from any of the other cells. This, together with the fact that methane production has begun within this study period in the two cells originally uncovered, indicates that the degradation process has become relatively stable in these two cells. This is further indicated by the low COD levels being produced in these cells during the last year of monitoring.

Water Budget:

The water budget for the four cells was determined for the period from May 1971 to May 1972 (Table 14). This period is used because by this time the cells were behaving consistently -- that is, all the cells had reached field capacity and were producing leachate regularly.

It is interesting that the evaporation percentages are nearly equal for all four cells, indicating that approximately 32 percent of incident precipitation becomes either runoff or leachate after field capacity has been reached. The effect of cover is to divide this 32 percent into approximately equal percentages of leachate and runoff. Without soil cover a larger amount of precipitation infiltrates and becomes leachate, while the evaporation rate increases slightly. As the surface attains more of a paper mache, and eventually a soil-like texture, the runoff percentage for this cell should increase somewhat.

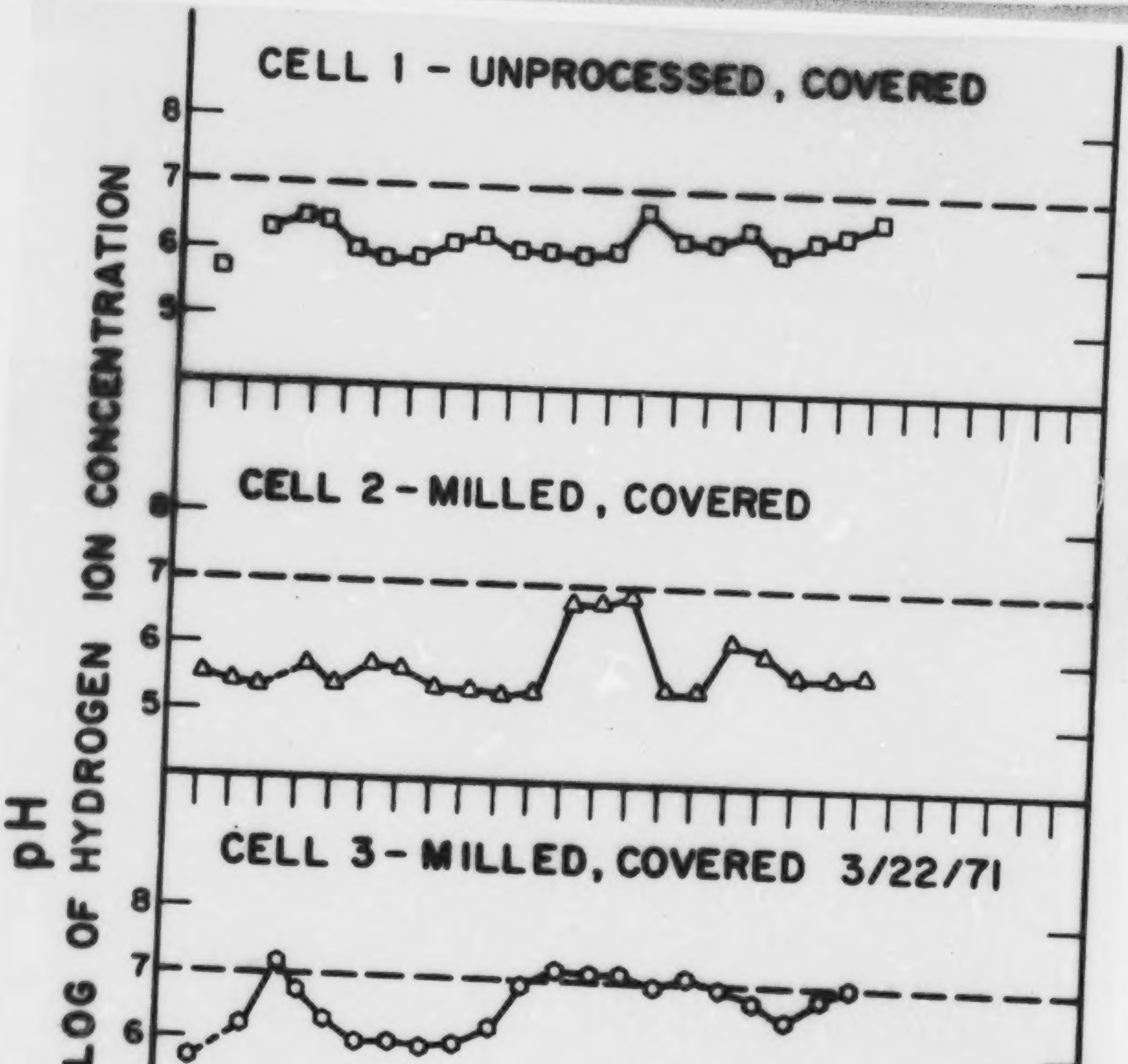


Figure 42. pH curves for lysimeters.

Direct comparison of the unprocessed covered cell and the milled uncovered cell corresponds quite well with the results from the Olin Avenue study. In addition, some further results of the present study include the fact that leachate production occurs at a faster rate in uncovered cells than in covered cells whether they be milled or unprocessed. While milling and lack of cover do promote a rapid achievement of a mature degradation system, both factors also allow larger quantities of organic matter to be leached out before formation of such a mature system has a chance to develop.

TABLE 14

WATER BUDGET

(MAY 1971 - MAY 1972)

	Precipitation (measured) Liters	Runoff (measured) Liters	%*	Leachate (measured) Liters	%*	Evaporation (by difference) Liters	%*
Cell 1	104200	15070	14.5	19018	18.2	70112	67.3
Cell 2	104200	15800	15.1	17551	16.8	70849	68.1
Cell 3	104200	13670	13.1	19249	18.4	71281	68.5
Cell 4	104200	288	0.3	28922	27.7	74990	72.0

*Percent of precipitation

Biotron and Gas Composition Studies

The Olin Avenue landfill and Oscar Mayer lysimeter studies produced valuable results, but they both had one drawback -- unpredictable and uncontrollable weather conditions. Thus a study of decomposition of milled and unprocessed refuse without soil cover and under identical conditions was undertaken in the University of Wisconsin-Madison Biotron. The Biotron is a controlled-environment facility in which a computer regulates and records parameters such as rainfall, light, humidity, and temperature.

Approximately 1,200 lbs. of each type of refuse were compacted under 10,000 lbs. pressure into two specially designed containers which were then placed in two separate but identical test chambers programmed to simulated a hot, humid climate with high rainfall (Figure 43). The test ran for 270 days, during which time data were collected from the refuse itself and from the leachate and gas produced. It is important to stress that the Biotron study differed significantly from the field studies in that the unprocessed refuse was not covered.

Both cells exhibited peak temperatures in the upper layer of refuse after one week. A rise in temperature deeper in the refuse beds occurred later and was closely related to the depth that moisture had penetrated into the cell. The highest temperature recorded was 102.0 degrees F for the milled and 102.5 degrees F for the unprocessed cell.

Of special interest in the Biotron study was the ability to closely monitor the movement of water through the refuse cells. Figure 44 presents the cumulative production of leachate from each cell and the cumulative amount of "rainfall" with time. The unprocessed cell began producing small amounts of leachate well before the entire volume of refuse reached field capacity and before steady leachate production was achieved. This is due to channeling, or relatively rapid downward movement of leachate, through the unprocessed refuse.

Figure 44 also shows that the unprocessed cell produced about 40 percent more leachate than the milled cell. Since no runoff was allowed from either cell, this difference attests to the increased capability of milled refuse to evaporate water in comparison with the unprocessed cell. Evaporation was about 30 percent of incident precipitation for the milled cell and 10 percent for the unprocessed cell. Note again that neither cell was covered.

Moisture sensing probes installed at various levels within each cell allowed direct monitoring of the movement of the moisture front through the refuse. Average penetration of the moisture front for the milled and unprocessed cells was calculated to be 3.03 and 3.02 inches per inch of percolated water, respectively. The moisture content change was from the original 14.9 and 16.1 percent water on a dry-weight basis to 138 and 116 percent for the milled and unprocessed cells, respectively.

Figure 45 shows the cumulative COD and Total Dissolved Solids (TDS) versus cumulative leachate volume. The Total Dissolved Solids is commonly considered equivalent in concept to specific conductance, because both tests are primarily a measure of the dissolved inorganic matter, or ions.

Figure 43. Container of milled refuse used in the Biotron Studies.

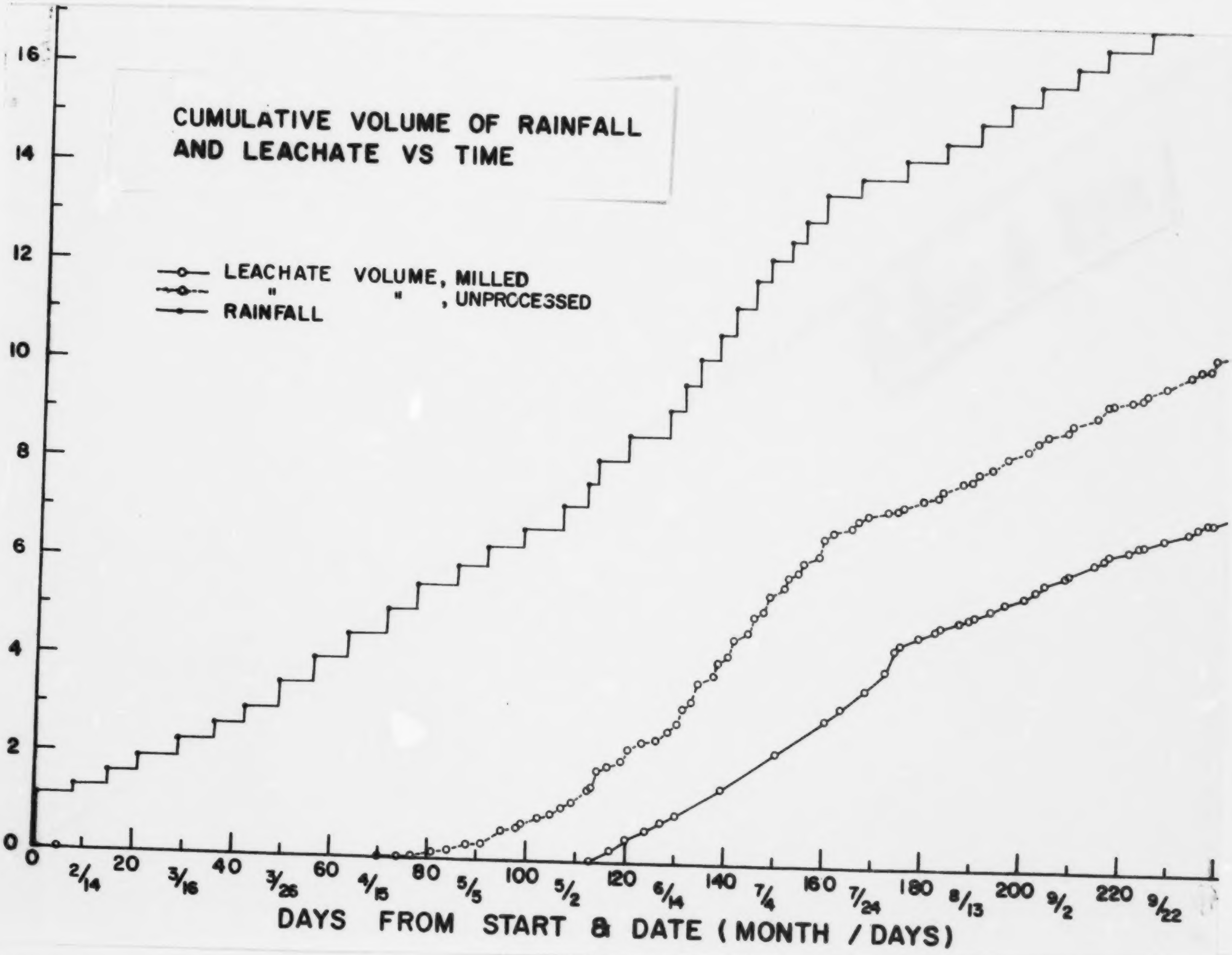


Figure 44. Cumulative volume of leachate and cumulative "rainfall" with time.

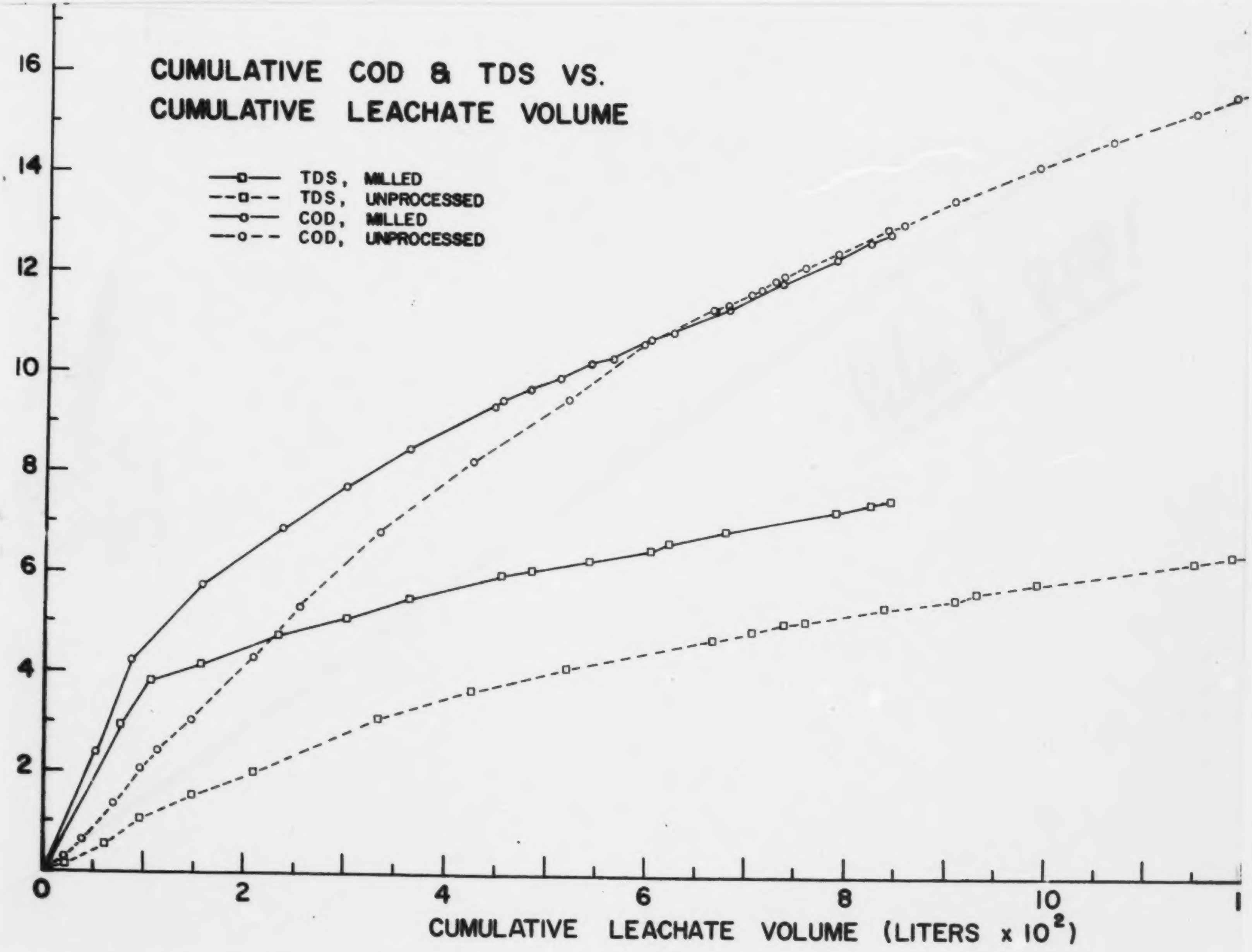


Figure 45. Cumulative COD and TDS vs. cumulative leachate volume from Biotron cells.

It is observed that the milled cell greatly outproduced the unprocessed cell during the initial stages of leachate production with respect to both COD and TDS. This is in keeping with the results of the field studies. After the initial accelerated rate of production, the milled cell tapered off to a lower rate of production of COD, such that for equal volumes of leachate production, the cumulative amount of COD produced was the same as for the unprocessed cell. In other words, the unprocessed cell never produced COD at as high a rate as the milled cell did initially; however, the unprocessed cell produced COD at its highest rate during the production of considerable volumes of leachate, such that in total effect the cells become equal.

The fact that the unprocessed cell curve extended to more total leachate, and that the unprocessed cell had produced more COD at the conclusions of the experiment, is related to the decreased ability of unprocessed refuse to evaporate water, since unprocessed refuse is not left uncovered in a landfill situation. No general conclusions will be drawn from this observation.

Similar analysis of the TDS curves shows that the milled cell produced TDS at an accelerated pace intially and then quickly dropped to a more moderate rate. The unprocessed cell, in contrast, produced TDS slowly, gradually increasing the amount produced to a rate equal to that of the milled cell (i.e., the two curves became parallel). Thus it is concluded that the milled cell produced more cumulative TDS at all stages of cumulative leachate production, and that the relative closeness of the total TDS production of the two cells at the conclusion of the experiment is largely a function of the increased leachate production from the unprocessed cell.

Except for some early pH values between 6 and 7, the pH remained very low (5.0 to 4.6) for both cells throughout the study. Since the Biotron project lasted a relatively short time, it would not be expected that pH would rise toward neutrality as it had in later stages of the field studies.

Gas:

The Olin Avenue, Oscar Meyer (lysimeter), and Biotron refuse cells were also outfitted to collect gas being given off by the decomposing refuse. The major gases sampled were oxygen, carbon dioxide, and methane.

Problems arose with the Olin Avenue studies when 9 of the 13 test cells proved unable to yield long-term gas data. Some useful results were salvaged, however. In general, it was noted that the concentrations of oxygen at deep levels in all cells were higher in early stages of the study than later. This indicates a change from aerobic to anaerobic conditions within the cells.

The levels of carbon dioxide did not vary much over the test period. This is probably due to some carbon dioxide being solubilized into the leachate at times of peak carbon dioxide production. Since the alkalinity of the leachate did increase during periods of substantial degradation, it seems likely that the increased carbon dioxide production was being solubilized by the leachate.

The methane concentrations remained low during the period of the Olin Avenue study, although they were higher in the milled uncovered cells than in the unprocessed covered cells. This finding corresponds with the leachate results which indicated that milled refuse undergoes decomposition more rapidly, and therefore enters a more stable, methane-producing stage more rapidly, than unprocessed refuse.

It was apparent at times throughout the test period that several of the milled uncovered cells had higher oxygen concentrations and lower methane concentrations than the unprocessed covered cells. These observations were difficult to relate to the leachate results, which always indicated that milled refuse decomposes more quickly than unprocessed refuse and should therefore be producing methane in larger quantities. It was therefore theorized that cover may be of considerable importance, limiting the passage of air (and oxygen) into, and methane out of, the unprocessed cells. Conversely, the absence of cover allows oxygen to enter more readily the milled uncovered cells and methane to leave. For this reason some doubt rose about the validity of using gas concentration data to compare cells with different amounts of cover, and thus only concentration changes, rather than absolute levels, were used to draw conclusions. Further studies were performed to provide more information on this matter.

The three milled cells in the lysimeter studies at the Oscar Meter site provided an opportunity to observe the effects of cover on gas composition in the cells under a wide variety of cover conditions. The gas composition data from the lower set of probes are given in Figure 46. Methane production occurred first in the two then-uncovered milled cells and since that time the methane concentration has been higher in these two cells than in the milled cell covered immediately. This indicates again that degradation to a stable state occurs more quickly in uncovered refuse. The fact that methane production remained more consistent in the milled cell which was covered after 6 months than in the uncovered milled cell and that it is present in larger concentrations seems to contradict the premise that degradation occurs at a faster rate in an uncovered milled cell. However, the presence of oxygen in larger quantities in the uncovered milled cell than in the milled cell covered later (shown better in the results from the upper probes, which are not given in this report) suggests that air and other gases can circulate more readily in and out of an uncovered cell. Thus methane can more readily escape, and oxygen more readily enter the uncovered milled cell than the covered cells. Measured gas compositions, therefore, must be viewed as products of gas transfer as well as gas production, especially in uncovered cells. Note that the unprocessed cell still had not begun to produce methane as of the close of the reporting period. This is another indication of the relatively lengthy period required before unprocessed covered refuse reaches a state of stable anaerobic decomposition.

The rate of gas production by the refuse, rather than simply the gas composition in the refuse, was analyzed in the Biotron studies. The inlet and exhaust air from the sealed test chambers was tested for

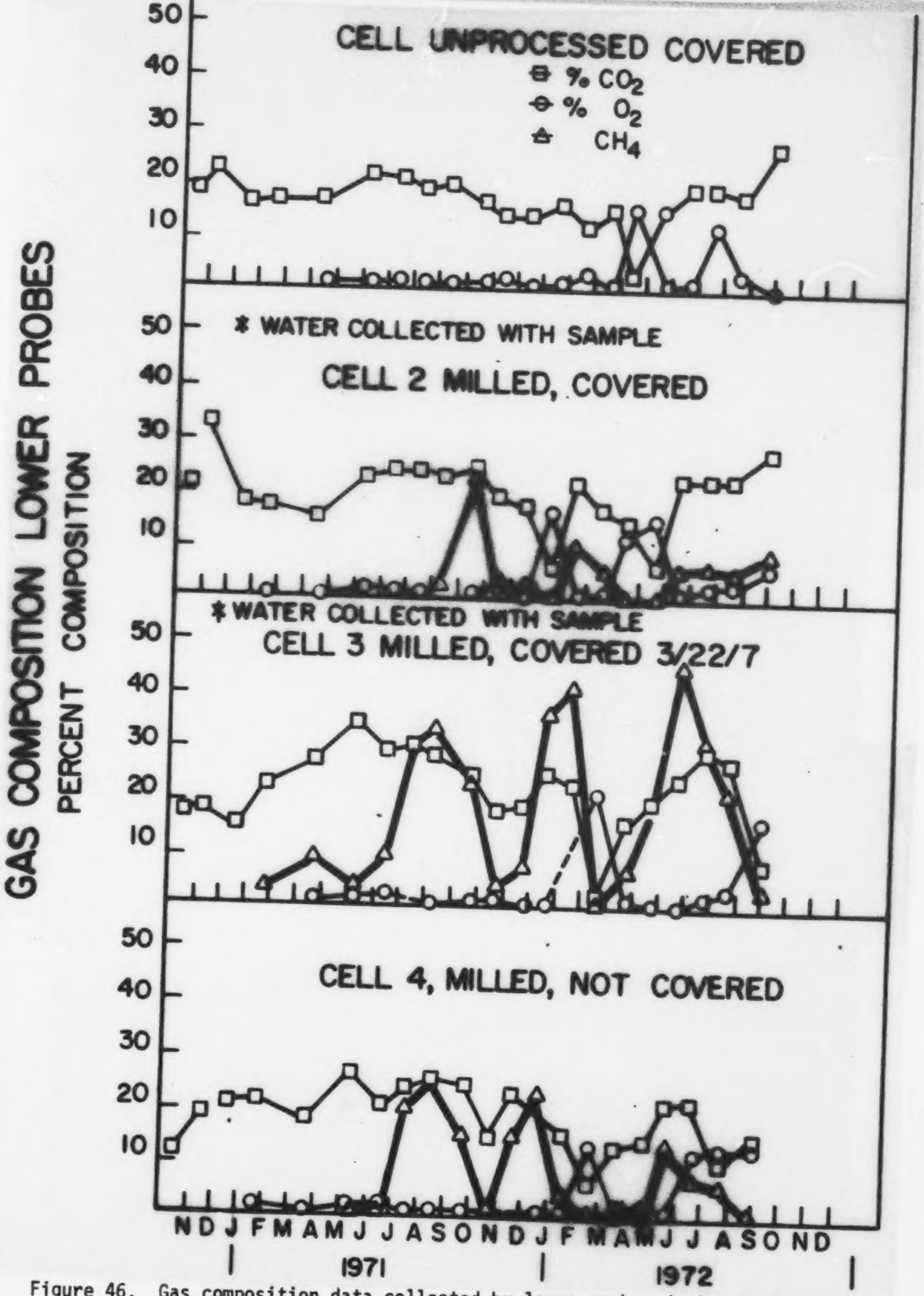


Figure 46. Gas composition data collected by lower probes during lysimeter studies conducted at the Oscar Meyer site.

carbon dioxide and methane and, knowing the rate of air flow, the production of these gases could be calculated. Concentrations of carbon dioxide peaked for both cells a few days after the start of the experiment. After the peak, carbon dioxide concentrations dropped to levels just slightly above the carbon dioxide levels in the supply air. The recorded concentrations were so low that it was suspected that most of the carbon dioxide produced was not being measured in the exhaust air. A calculation based on pH and alkalinity data was made to estimate the amount of carbon dioxide dissolved in the leachate. It was found that less than 0.2 percent of the total carbon dioxide production escaped as gas, the rest being dissolved in the leachate.

The same problem was not as likely with methane, which has a very low solubility in water. Methane production was negligible for the first 80 days, as would be expected during aerobic decomposition. After 176 days an apparent rapid increase in methane production occurred in both cells. During the remainder of the test period, methane concentrations remained relatively high with an average of 23 ppm for both cells (compared with an average methane concentration of 2.78 ppm in the supply air). Despite this significant rise at 176 days, the total 270-day production of methane was just 0.052 cu. ft. Thus, methane production during the experiment was virtually negligible, as would be expected in cells that had not reached neutral pH levels in leachate, and the attendant stable anaerobic stage of decomposition.

Vectors

Studies were undertaken to compare the relative attraction of milled and unprocessed refuse to two major vectors -- rats and flies. Efforts were also made to determine whether rats and flies could survive in milled refuse.

Rats:

Field studies of rats were conducted at the Olin Avenue test cells in 1968. Because the two basic cell types -- milled uncovered and unprocessed covered -- were intermixed through the Olin Avenue site, they could be compared with respect to rat infestation.

Thirty bait stations using bait without poison were placed as uniformly as possible over the site (Figure 47). The bait containers were weighed regularly to determine the amount of bait loss. The consumption of bait was considered to be proportional to the amount of rat activity in the vicinity of the bait station. Other evidence, such as droppings, presence of tracks, and new burrows, was also recorded.

In the test's first phase, the bait stations were set up to reveal initial areas of rat activity. Results did not show a preference between cell types. The highest take occurred in a station located on the special garbage cells. Since garbage is an obvious attractant, the rats were probably living on this cell before the bait stations were placed. This conclusion was supported by burrow counts and rat sightings on and adjacent to the garbage cells.

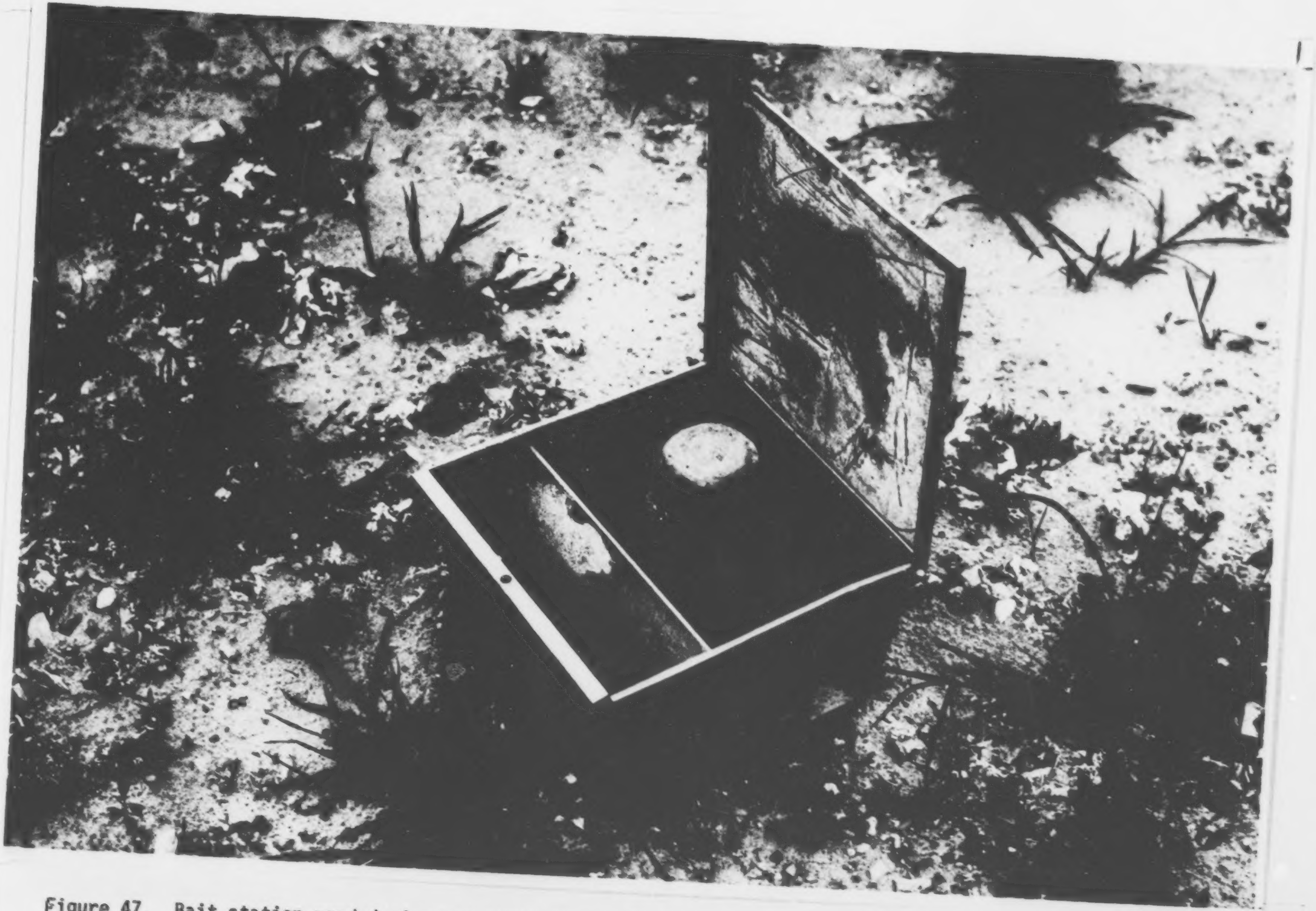


Figure 47. Bait station used during rat study phase of vector investigation at Olin Avenue Site.

With the remainder of the stations, the highest takes occurred on the edge of the test site. This led to the conclusion that rats preferred the peripheral area of the site more than they preferred either milled or unprocessed refuse cells.

In the next phase, the bait stations were moved to new locations. If the stations did not draw rat activity with them, it would indicate that the previous areas of activity were so desirable that rats would not leave them to seek out a bait station. If the new stations did draw activity, it would be important to note which cell type -- milled or unprocessed -- had the greater increase. Since the stations were identical, the rats would base their choice of a new site on considerations other than the presence of a bait station.

Nearly all of the original stations were removed and nine stations were established in the central area, where previously there had been negligible activity.

The results showed that rat activity was drawn readily for distances up to 100 feet. This migration led to much test drilling, resulting eventually in 18 new burrows. Of these, 12 were on the two unprocessed covered cells while six were on one of the four uncovered cells. Thus, it appears that the unprocessed covered cells provided better drilling and living conditions than did the milled cells (minimum of 6 inches compacted cover).

The fact that rats were drawn by the bait in the second phase does not negate results from the first phase, since the rats were undoubtedly dependent on the bait after 70 days of the first phase.

The final phase of the rat field tests involved adding poison to the bait and observing the rate of kill. To assure a thorough kill, the bait stations were returned to their original locations and were replenished with nonpoisoned bait. This was continued for 3 weeks prior to poisoning to foster dependency by the rats on the bait stations. Three to nine days after the addition of 5-percent-by-weight anticoagulant rodenticide to the bait, the kill was essentially complete. The rate of decrease of bait take was higher on the milled cells than on the unprocessed cells. This may or may not properly suggest that rats frequenting the milled cells were more dependent on the bait for food than were rats associated with unprocessed refuse.

It was noted during these tests that any irregularity in the surface of a cell, whether milled or unprocessed, was likely to lead to test drilling or a burrow. Erosion of cover material, for example, produces irregularities which may lead to test drilling. In milled uncovered cells a break in the surface is not as likely to occur, and if it does occur it is not as likely to result in burrows. This is because the interior of milled cells offers only more of the same material as is found on the surface. Many signs of test-drilling without burrow development were found on milled cells.

The field studies suggested that milled refuse without cover was less attractive to rats, especially for burrow development, than was unprocessed refuse covered with soil. It remained to be shown, however, whether milled refuse by itself would attract rodents. To determine this, several tons of milled refuse were placed in a remote location within a Madison residential area. A snow fence was set up to enclose the refuse and discourage spreading by children. The site was checked periodically for signs of rodent activity. No activity was observed at any time and after 12 months, the test was terminated.

The above test could not be considered conclusive, since there was no assurance that rats were living in the area, nor was there reason to expect that any rats nearby would leave their previous surroundings in favor of milled refuse. Consequently, a similar pile of milled refuse was placed in a remote location at the Olin Avenue landfill where rats were known to be present. After several months, no signs of activity were noticed, and the test was ended.

It is felt that the combination of field tests on rats and refuse provides rather conclusive evidence that milled refuse as processed at Madison will not result in rat infestation at a landfill. The fact that no rats have been sighted in the landfill in over four years since the rats were poisoned, and that a mother duck has felt sufficiently secure to develop a nest, lay, and hatch eggs near the center of the site, supports the findings of the study.

Since the conclusions of the field test were strictly applicable only to Madison, cage tests were performed in which rats were forced to depend solely on milled refuse for sustenance. It was felt that the results of these supplementary tests would have wide applicability since they would show that rats either can or cannot survive on milled refuse.

The tests were conducted at the Purdue University Rodent Test Center at Lafayette, Indiania (Figure 48). The facility is maintained jointly by the school's Rodent Control Fund and the United States Department of Interior for testing baits and poisons. Some 750 Norway rats (Rattus norvegicus) are kept in two large areas where they can live under nearly normal conditions until they are trapped for test purposes.

Prime Norway rats, each weighing over 200 grams, were used for the tests. Five males and five females were placed in each test cage. The metal cages were 3 x 7 x 2 ft. high (Figure 49).

Three test series were run. For the first series, the test cages were kept inside at 70 degrees F and in total darkness. For the other two series, the tanks were kept outdoors under mild summer conditions; these tanks were covered to maintain darkness. All tests were conducted to a logical conclusion or over a 15-day period, whichever came first.

Figure 48. Rodent Test Center for Norway rats at Purdue University, Lafayette, Indiana.

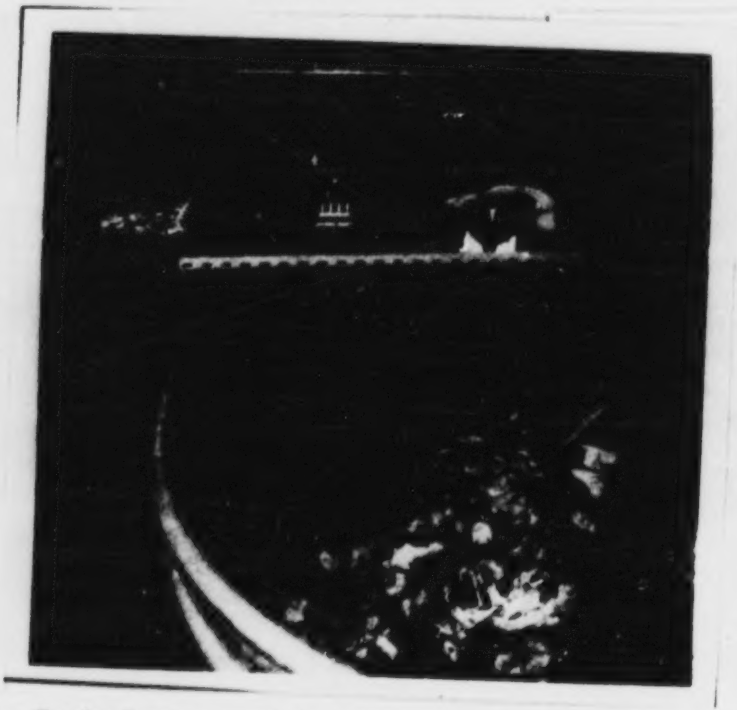


Figure 49. Typical cage used in studies conducted at Purdue University.

The first series was run in 1969, when fresh milled refuse with about 15 percent (wet-weight basis) garbage content and two-year-old milled refuse of approximately similar garbage content were used. All refuse samples were sent to Purdue from Madison. Some 30 lbs. of each type of refuse were placed in separate test tanks, replenished as necessary to assure the availability of over three times the minimum daily nutritional requirements of the rats at all times. For purposes of calculation, only the food wastes or garbage content of the refuse was considered to be edible by and nutritious for the rats.

In the tank with aged milled refuse, the rats dug holes and scattered the heavy, compact material in search of food. All animals showed weight loss by the end of the fourth day. During the fifth night, one animal was cannibalized. All but one animal had been eaten by the end of the test, and the survivor died the next day. The results were virtually identical when the test was repeated.

Although there appeared to be more available food in the freshly milled refuse than in the aged, it was not sufficient to sustain the rats. During the first test, two animals were cannibalized on the eleventh night. Only three animals survived the 15-day test, and they were so weak that they had to be killed. Again, similar results were obtained during a replication of this test.

The conclusion of this series of tests is that freshly milled or aged milled refuse, as received from Madison, cannot sustain a rat population.

In the next test series conducted in 1972, freshly milled refuse samples with various fractions of garbage were used. The four levels of garbage content tested were 17, 32, 47, and 59 percent wet garbage on a wet-weight basis. No animals died as a result of starvation or cannibalism during this series of tests. It was quite obvious, however, that the samples sent to Purdue had been poorly milled, or perhaps were not milled as a result of procedural problems during sample preparation at Madison. Thus, large chunks of putrescrible matter which could be used as food were available to the rats, and they survived. Obviously, then, particle size is of special importance in determining the suitability of milled refuse to sustain rats.

The third series, conducted later in 1972, was designed to correct the problems encountered in the previous test series. Special care was taken to obtain a representative milled product for the two samples, which contained approximately 10 and 20 percent wet garbage on a wet-weight basis.

In the 20 percent cage, all the rats died within 10 days. in the 10 percent cage, five animals survived the full 15 days and one dominant male seemed to thrive quite well, although the others were very weak. Although these results are not quite as conclusive as other tests had been, the results of this final series still leads to the conclusion that rats cannot survive indefinitely on a diet consisting only of milled refuse containing up to 20 percent garbage on a wet-weight basis. Based on this fact, there is very little possibility of rat infestation and survival in a milled refuse landfill.

Since the fall of 1966, when the rats at the Olin Avenue test site were poisoned, only two or three rats have been observed on the landfill or the vicinity. Many City and University personnel regularly inspect the Olin Avenue site but since 1968 have observed no burrows that can be attributed to rats.

It has been necessary to institute a rodent-control program at the milling plant, however. Rats and mice are continually transported to the plant in refuse packer trucks and must be poisoned on a regular basis. No migration from the mill building to the landfill has been observed.

Flies:

Field studies at the Olin Avenue test site as well as laboratory studies were conducted in the summers of 1968 and 1969 to evaluate fly problems which might arise from not covering milled refuse in a landfill.

A comparison of the relative numbers of flies on or near each of the two cell types at the Olin Avenue landfill was made by direct count. The testing was done using a Scudder Grille to attract the flies for counting (Figure 50). This is a standard test procedure to evaluate fly populations in barns, etc. The results indicted no marked differences in the number of flies on milled uncovered or unprocessed covered refuse cells.

Another study was designed to determine the relative numbers of flies emerging from comparable amounts of milled and unprocessed refuse (Figure 51). Screened cages were placed over similar piles of each kind of refuse, about 1000 pounds of refuse in each case, and the files in each cage were counted periodically over the 1 month duration of the test (Table 15). The cage over the unprocessed refuse (without cover) reached a population of some 4000 flies while the greatest number observed in the cage over milled refuse was 15.

To determine whether the lack of flies emerging from milled refuse was due to lack of viable maggots or to the inability of milled refuse to support flies, 1200 flies and 2000 maggots were introduced into the cage over a second pile of milled refuse. In this case, the flies survived for about a week, but the maggots were unable to complete their life cycle and thus did not produce more flies.

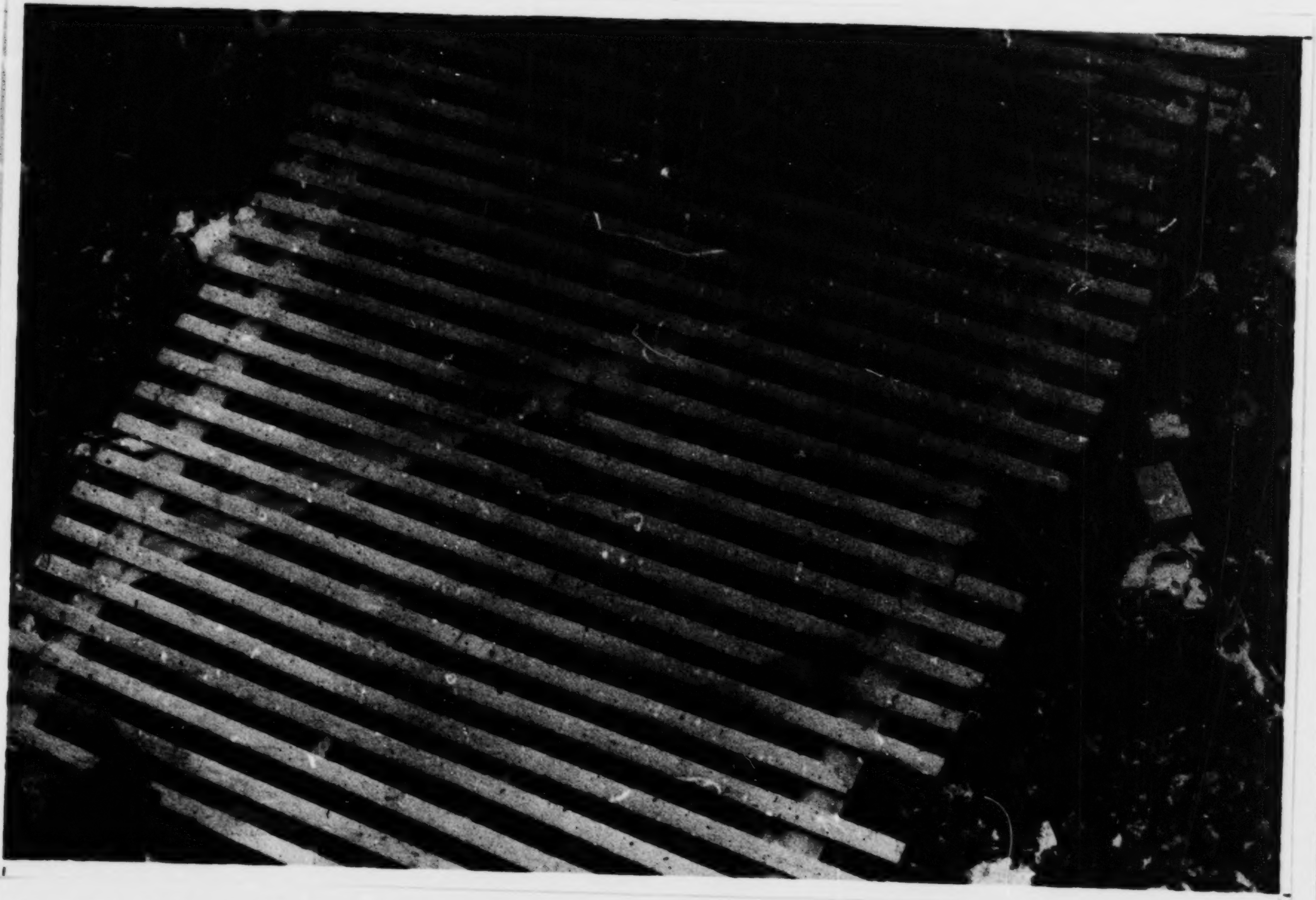


Figure 50. Scudder grille used to determine numbers of flies on milled and unprocessed refuse.

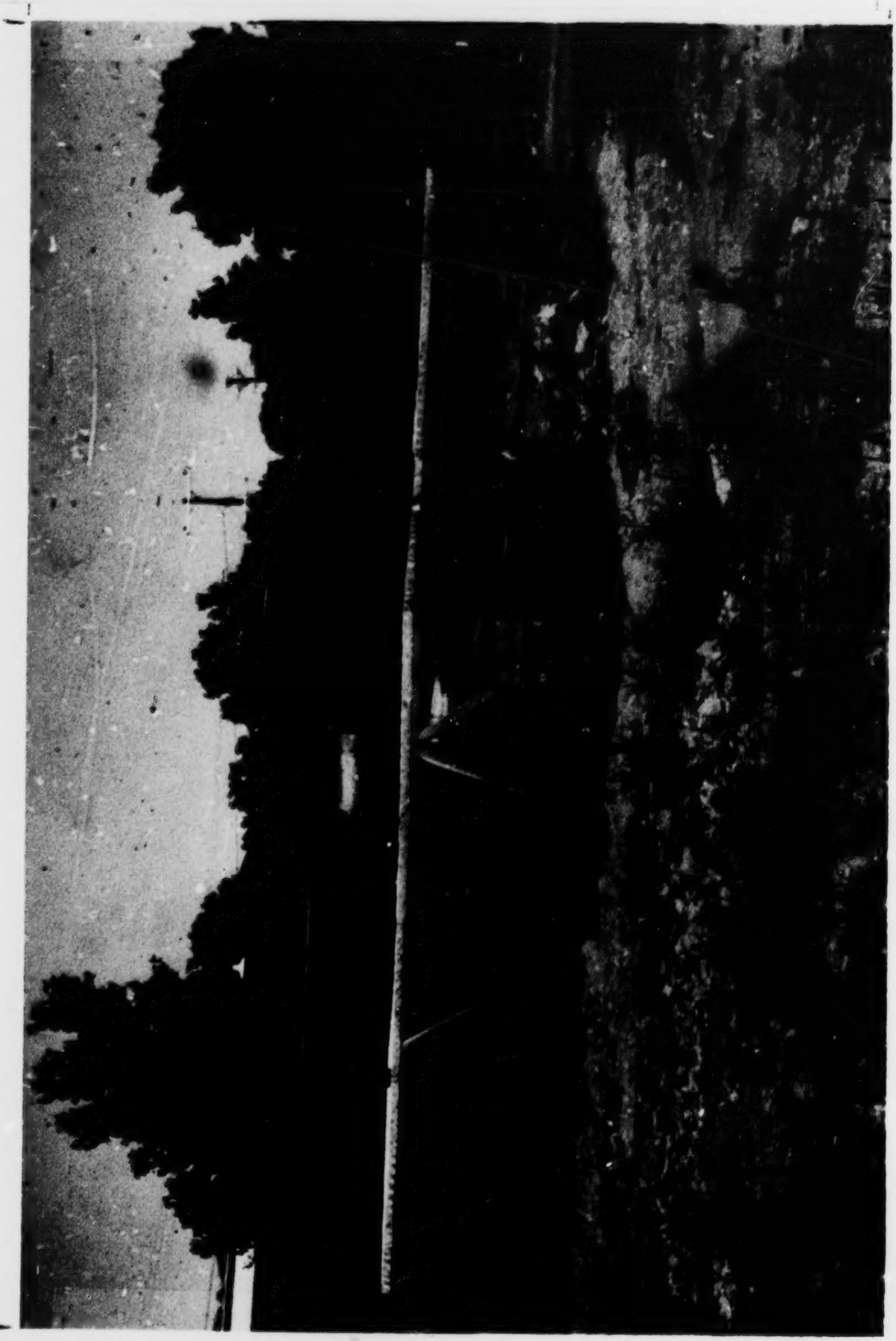


Figure 51. Screened cages used during fly survivability tests, 1969.

TABLE 15

RESULTS OF FLY CAGE TESTS (1969)

Days	Cage 1 Unprocessed, Compacted	Cage 2 Milled	Cage 3 Milled
0	More flies than cages 2 or 3	-	-
1	Approximately 1000 flies	10 flies	15 flies
6	Approximately 1000 flies	none	none
12	Approximately 4000 flies	1200 adult flies and 2000 maggots introduced	none
15	Remaining at large number	Approximately 100 flies*	none
20	Remaining at large number	2 flies**	none
21-30	Number beginning to decline	none	none

* Indicates most adult flies survived.

**Indicates maggots were unable to complete life cycle and that initial 1200 adult flies had died.

Continuing this line of investigation, samples of fresh and 6-month-old milled refuse were used for laboratory studies to determine whether this material can support flies. Approximately 1000 fly eggs were introduced into separate cartons containing fresh and aged refuse. Similar cartons had no eggs added. The refuse was kept moist and humid (40 to 70 percent relative humidity) and warm (80 degrees F) for 3 weeks. These conditions are commonly cited by entomologists as "optimal" for growing flies.

With the freshly milled refuse to which no eggs were added, no flies emerged throughout the test. In the carton of fresh refuse to which 1000 eggs had been added, approximately 1000 flies emerged at the end of 3 weeks. Thus, when fresh milled refuse is subjected to optimal environmental conditions, it is capable of supporting the growth of flies.

With the 6-month-old refuse to which no eggs were added, a few flies did emerge, but these were not houseflies. They probably arose from eggs or maggots picked up by the refuse while it was in the landfill. The aged refuse was not able to support the life cycle of the added eggs, for approximately the same number of flies emerged as compared to the carton of aged refuse to which no eggs were added.

Thus, under "optimal" conditions, including controlled refuse moisture content and proper temperature and humidity, fresh milled refuse can support the fly life cycle. Aged milled refuse, however, is a poor medium for housefly development even under optimal laboratory conditions.

It remained to show whether maggots are killed during passage through a hammermill. On two occasions, the Gondard mill was cleared by stopping the feed conveyor. In the first trial, 6000 mature housefly maggots were scattered on about 100 lbs. of refuse on the conveyor. This refuse was then run through the mill. The second trial was identical, except 12,000 maggots were used. The emerging refuse was examined for living maggots. The milled refuse was then exposed to ideal environmental conditions in the laboratory to insure that any viable maggots which were overlooked would emerge as flies. In refuse from the first trial, no flies emerged; in the second 84 flies were counted.

It is possible that some maggots were lost in the mill, although care was taken to avoid this. The most likely explanation for the large decrease in viable maggots is that most of them were macerated during the milling process.

The fly studies showed that there are several mechanisms which would lead to reduced fly populations at landfills with milled refuse without cover. First, the milling process itself destroys the great majority of maggots. Second, freshly millled refuse can support the fly life cycle only under optimal environmental conditions that are not normally found in a landfill. Finally, when refuse has aged for several months, even this ability under optimal conditions is destroyed.

Not one of the tests described above provides absolute proof that no fly problems will ever exist with milled refuse. Taken together, however, the evidence from these tests becomes quite conclusive. Five years of experience at the landfill support the conclusions of this study, for there have been few flies reported on the milled refuse at the site.

Vegetation

Trees:

A study was initiated at the Olin Avenue site in 1969 to determine the ability of milled refuse to support tree and shrub growth. The type and thickness of cover soil as well as tree and shrub species were varied to determine which combinations gave the best growth. Experimental plots were established on both milled and unprocessed refuse to determine if there were any differences in growth due to the composition of the underlying refuse. Additional plots were established to determine the effects of fertilizer on the growth of tress on the landfill. Ten species of trees and shrubs were planted.

Growth measurements were made on all ten species planted, but only white ash, jack pine, red pine and buffaloberry were selected for representative analyses (Table 16).

Soil type was found to be a significant factor in producing growth differences in a single year. Most of the species other than jack pine increased in height and diameter more on topsoil than on subsoil. This is reasonable because the low fertility of the subsoil was probably adequate for the low-demanding jack pine.

Many trees (19 percent) died the first year of the study. The much greater initial mortality on the unprocessed site as compared to the milled site is attributed to differences in the condition of the planting stock and soil at the time of planting. Greater initial mortality occurred on the unprocessed topsoil block than on the unprocessed subsoil block; this difference can be partially explained by the greater weed competition on topsoil than subsoil.

Studies of plant growth on spoil banks have indicated that most tree mortality occurs the first year after planting, with very small increases in mortality occurring in later years. The results of this study disagree with this finding. Little additional mortality occurred on either site until the fall and winter of 1971-72 when a rapid upsurge in mortality (65 percent in total) occurred; this later mortality was attributed to a lack of adequate soil aeration. One reason for this hypothesis is that all species survivied better as of 1972 on topsoil on the milled site while all species did better on subsoil on the unprocessed site. The better survival on topsoil on the milled site is probably because the topsoil had 15 cm. more soil cover than the subsoil. This extra soil acted as a buffer between the tree roots and gases produced by the decomposing refuse. Since the trees also had better survival on the unprocessed than the milled site, it was suspected that gas production by milled refuse was greater than for unprocessed refuse, as discussed earlier in this report.

TABLE 16

EFFECT OF PLANTING CONDITIONS ON TREE GROWTH (PERCENT)

(November 1970 to September 1971)

Plot*		White Ash Hts.	White Ash Diam.	Red Pine Ht.	Red Pine Diam.	Jack Pine Ht.	Jack Pine Diam.	Buff Diam.
Milled	(A)	(1)	(1)	2.8	8.0	29.3	19.7	32.6
	(B)	43.0	51.3	2.8	3.5	41.6	34.2	27.5
"	(C)	23.5	28.4	1.6	10.6	12.8	9.4	6.7
"	(D)	53.7	61.5	11.1	19.6	(3)	(3)	30.2
"	(E)	48.4	47.6	14.8	18.6	19.0	4.7	33.5
"	(F)	50.5	70.4	18.9	20.6	25.8	17.8	35.7
Unprocessed	(A)	27.6	15.1	9.9	5.5	6.6	7.6	57.6
"	(B)	61.7	38.2	10.1	13.0	11.1	18.8	55.6
"	(C)	93.8	54.9	11.2	8.8	12.9	14.6	67.8
"	(D)	71.1	69.2	13.0	27.2	29.1	10.6	39.2
"	(E)	41.7	71.4	(2)	38.0	24.6	16.7	87.7
"	(F)	19.7	24.6	(2)	9.0	17.3	15.1	12.3

* Plot A - 15 cm. subsoil
B - 30 cm. subsoil
C - 45 cm. subsoil
D - 45 cm. subsoil
E - 30 cm. subsoil beneath 15 cm. topsoil
F - 15 cm. subsoil beneath 15 cm. topsoil

Notes
1. No measurements taken
2. Tops of trees were damaged, limiting growth.
3. All trees had died by September 1971.

Compaction caused by grading operations on the study sites greatly influenced the moisture, aeration, and strength characteristics of the soils, and thereby reduced growth and efficiency of the root system. Greater tap root and overall root penetration occurred on the unprocessed than on the milled site. However, the amount of top growth did not always correspond to the size and vigor of the respective root system.

Because of compaction, the soils had both low total water capacity and low available water capacity. The compaction also caused the formation of a crust which intensified dry soil conditions by causing much rainfall to run off. Large amounts of rainfall were sufficient to completely saturate the soil pores, but the low hydraulic conductivity and high moisture retention then caused the pores to drain very slowly, greatly intensifying soil aeration problems.

Soil aeration on the site is very poor. The production of carbon dioxide and methane by the refuse, in conjunction with the low amounts of gas-filled pore space, provides a great obstacle for growing trees. Thus, it can be seen that the high mortality in the fall and winter of 1971-72 was probably due in part to insufficient oxygen present in the rooting zone.

Measurements indicated that the refuse had no detectable effect on the soil temperature and that the fertility status of the landfill soils is generally adequate for tree growth. It appears that the factors limiting tree growth are more likely physical than chemical.

Because root systems were limited in extent and function by deficient moisture, deficient oxygen, or high soil strength, fertilizers were apparently not utilized by the trees in sufficient quantities to cause measurable growth changes.

Recommendations concerning site preparation, tree planting, and cultrual practices to maintain trees on landfill sites, will depend upon the proposed use of the landfill, the composition and preparation of the refuse, the kinds of soil materials available, and the characteristics of the site. Choice of a species depends upon use since trees grown for aesthetic reasons should be chosen primarily on the basis of survival and appearance while overall growth is more important for economic purposes. The refuse composition and preparation will also influence these choices since the type and amount of gas production is determined by the refuse and may contribute significantly to deterioration and death of trees.

A medium texture, well-structured soil material should be applied to the refuse using a method which limits compaction as much as possible around the base of the planted tree. The depth of soil material should be as great as is economically feasible, providing adequate soil volume for root expansion and a buffer between root system, and gases produced by the refuse. Species to be planted should have the ability to develop lateral root systems with diffuse branching; white ash and crab developed such roots in this study. Relatively small seedlings should be planted in planting holes which have mulch material and fertilizer packets added.

Small seedlings can more easily adapt their root systems to the environment in which they are planted. In cases where the planting of larger trees is more desirable, planting holes should be backfilled with topsoil and a mulch material to provide a good initial root environment.

Other Vegetation:

Unless an uncovered cell of milled refuse is continually worked, volunteer vegetation will develop within one or two years after placement. During the summer of 1968, a diverse plant community, ranging from weeds to garden vegetables to trees, became established spontaneously on all the milled uncovered cells at the Olin Avenue site. This growth may have been due in part to seeds in the refuse itself. Heavy plant growth has continued on the milled cells in subsequent years. In fact, the vegetation of the milled refuse cell is so dense that it is difficult for an observer standing on an old milled refuse cell to see that he is indeed on refuse and not on soil (Figure 52).

Also in 1968, a slimy growth was noted on many of the milled uncovered cells. It persisted throughout the summer and reappeared the next year. It was identified as a slime mold, *Fuligo septica*, which is commonly found in heavily wooded areas. It grows on material of high cellulose content. This slime mold is not a threat to public health.

Fires

In August 1969, the Madison Fire Department evaluated fire hazards on uncovered milled refuse. A freshly constructed cell and one that was over a year old were used for the tests at the Olin Avenue site. The older cell had a cover of vegetation which was bulldozed off prior to the tests. Moisture levels in the cells were lower than average as a result of prolonged dry weather.

Attempts were made to ignite the cells by several methods which simulated potential fire sources in actual landfill situations. Surface fires were started by igniting oil which had been poured on the cells and by igniting dry hay placed over the refuse. In all cases the refuse smoldered but did not support flames once the oil or hay had burned completely. Even though fans were used to create a 8-mph wind during the hay tests on the aged refuse cell, combustion spread only 25 feet after one hour. With fresh refuse, surface propagation did take place, although no flames were evident. The smoldering remained on the surface in all cases and was easily extinguished by water spray or soil cover (Figure 53).

A fire starting from flying embers was simulated by placing hot charcoal briquettes on the surface of the two cells. The charcoal had virtually no effect on the aged cell. On the freshly milled cell, however, combustion began slowly and spread, eventually encompassing the entire cell surface. In this case the combustion was also limited to the cell surface where it could easily be controlled.

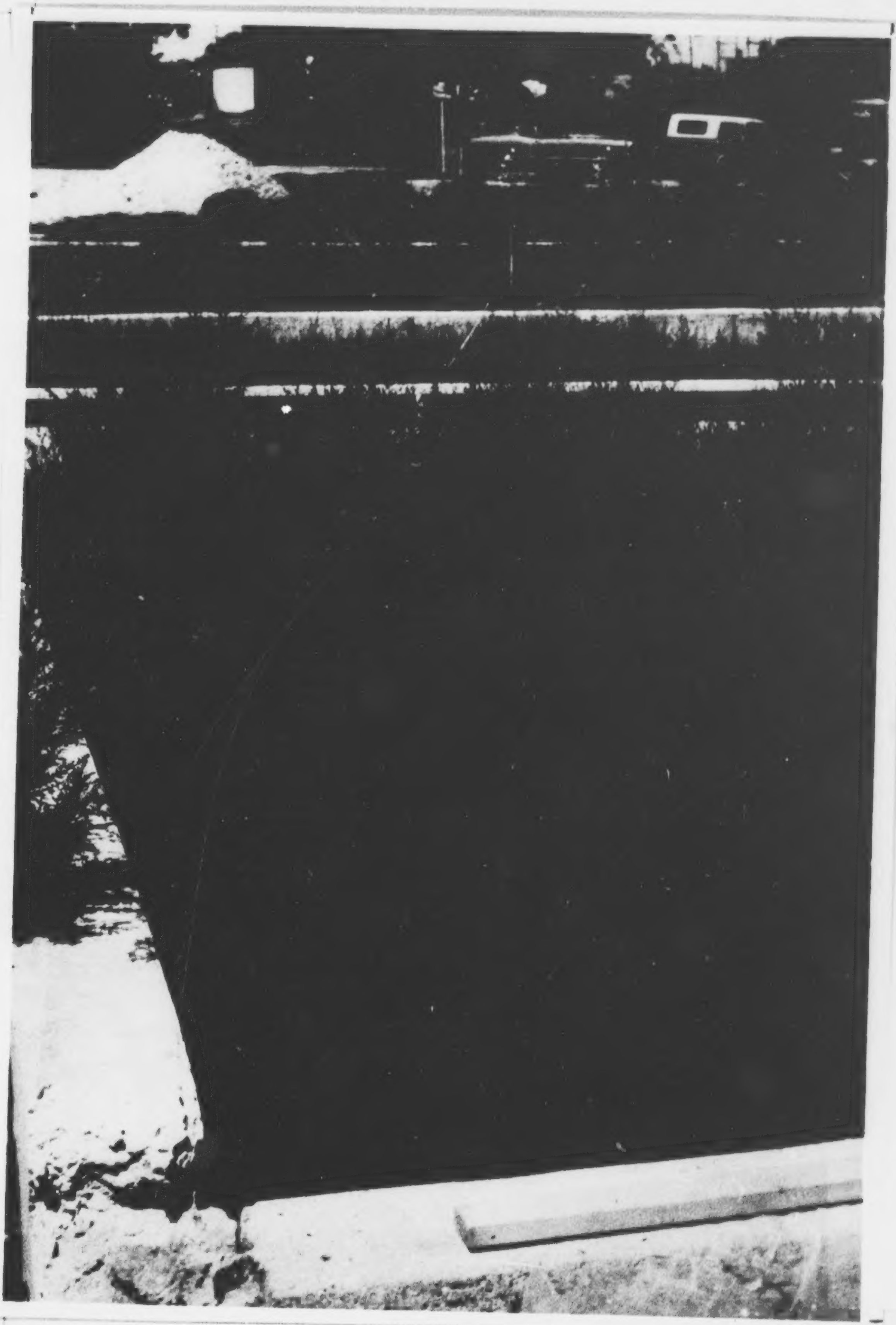


Figure 52. Heavy vegetation growing on a test cell of milled refuse.

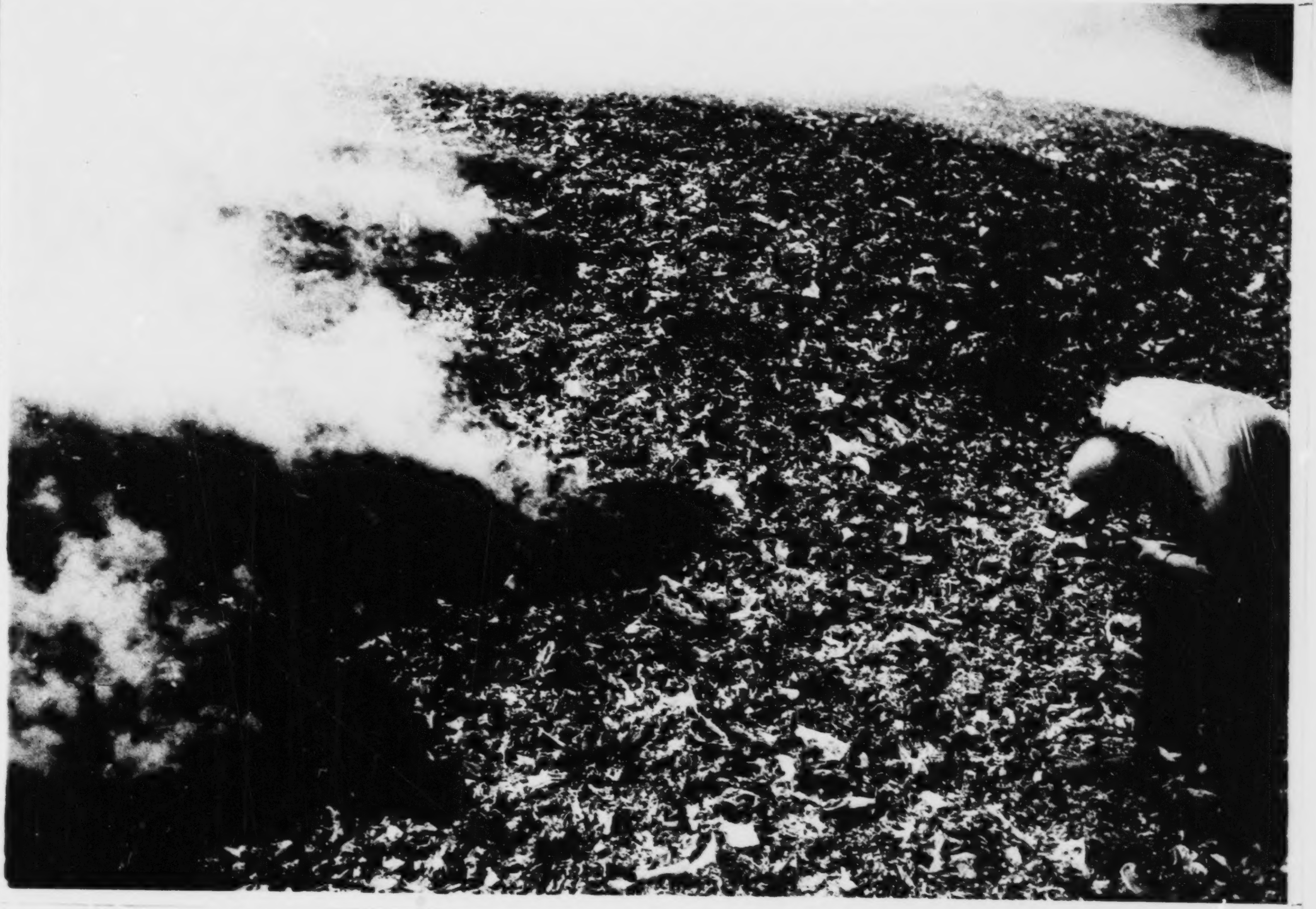


Figure 53. Fire deliberately started on fresh milled refuse caused smoldering, but remained on the surface and was easily extinguished.

To simulate spontaneous internal combustion, a 1,200-watt electric heating element was buried 3 feet deep in each cell. The element produced a temperature of 1,500 degrees F for 20 hours. In both cases, refuse within an inch or two of the element was charred, but no combustion occurred.

In summary, flameless combustion was supported by aged milled refuse, but the combustion did not spread. A slowly spreading fire was produced on the surface of the freshly milled cell. In both cases the combustion could be arrested with water or soil.

The results of the fire tests were supported by an experience during a dry spell in the spring of 1970, when a fire, apparently begun by a lighted cigarette, began on a milled refuse cell. The fire burned on the surface but did not penetrate to the interior of the cell. It was extinguished by surface compaction with a front-end loader.

It is believed that the combination of a lack of voids and the ready venting of flammable methane to the atmosphere is primarily responsible for the lack of fire potential in piles of uncovered milled refuse.

Odor and Esthetics

The Olin Avenue landfill is bounded by a playfield on one side, residential areas on two sides, and the Dane County Coliseum on the other The Coliseum is a 10,000-seat facility. Thus, there was a large "audience" available to make known their complaints if any odor problems developed. Fortunately, no such problems have occurred.

The lack of unpleasant smells is one of the most notable features mentioned by visitors to the milled refuse landfill areas. Project personnel theorize that ready access to air and the accompanying drying of the surface of the milled refuse cells produce an aerobic buffer zone which treats or modifies odors produced deeper in the cells. In support of this theory, it is noted that by digging 3 to 6 inches into a cell, one begins to detect odor typical of decaying refuse. Upon digging a foot or more, a most disagreeable odor is produced.

Some minor odor problems have developed during unusually wet periods when, due to improper drainage of depressions between the test cells, ponds of water formed. These problems have been readily solved by filling the low areas or by providing drainage channels.

As noted earlier, milled refuse is relatively homogeneous and looks like oversized confetti. Viewed from a distance, milled refuse is nondescript and unobnoxious since it contains no large recognizable items. Of the thousands of lay people who have viewed the Olin Avenue landfill, no one has objected to the sight of uncovered milled refuse. An independent evaluation of the public acceptability of the Olin Avenue reduction plant and landfill was published in Compost Science in the January-February 1973 issue.

Use of Cover

Cover soil is generally prescribed for a sanitary landfill to hide the refuse, to reduce odors, to control blowing paper, to lessen the danger of fire, to discourage vectors, and to limit leachate and gas production. As we have seen in preceding sections of this report, most of the problems solved by covering unprocessed refuse are similarly reduced or eliminated by landfilling milled refuse without cover. In other words, the initial European claims for milled refuse have been substantially borne out during the Madison demonstration project.

Except for possible considerations of groundwater contamination due to rapid initial pollution loads in leachate from milled cells, it appears that no daily cover is necessary. And, in fact, the question of groundwater contamination is more dependent on local hydrogeological considerations at the landfill site than on differences between milled and unprocessed refuse. Thus, it is possible that in a multilayer milled refuse landfill, the exposed layer may remain uncovered until tne next layer is placed on top of it. This sequence could be followed until the landfill reaches final grade. (Some intermediate cover may be required if final grade is not reached in a reasonable period, such as 6 to 12 months, or if local conditions dictate such procedure.) Once final grade is achieved, the milled refuse should be covered to prepare and reclaim the landfill site for other uses.

During construction of the Olin Avenue test cells, it was the practice to cover the top and sides of the unprocessed refuse cells but not the daily working face. This amounted to what is commonly called intermediate cover. The corresponding milled refuse cells were normally not covered; however, special tests were conducted to estimate cover soil requirements after a milled refuse landfill has been brought to final grade. Based on these tests, it is felt that a practical depth of dirt to cover milled refuse completely and smoothly is 6 inches. In comparison, a practical depth of cover dirt on unprocessed refuse was found to be 14 inches on the top and 18 inches on the side of a cell using the same equipment as with the milled cells. This amount of cover provides a uniformly smooth and refuse-free surface of the same quality as did the 6 inches of cover on the milled refuse. Although some landfill operators will disagree with these figures, the ratio of the cover required for equal quality of the finished surface for milled and unprocessed refuse is felt to be valid.

This difference in cover requirements for the two cell types is due to the more even surface that can be obtained with milled refuse. Spreading, compacting, and filling unprocessed refuse is more difficult than for milled refuse due to the extremely variable compactability of the hetrogeneous unprocessed refuse which results in problems in obtaining a level surface. The differences in compactability result in the bulldozer leaving an uneven surface for unprocessed refuse which is more difficult to cover completely. Milled refuse, on the other hand, is easy to spread evenly without local depressions or rises because of its smaller and more homogeneous particles. Also, the smaller particles of milled refuse are not as readily pulled up by bulldozer tracks during compaction or pulled up through the soil during covering operations.

To give an indication of the monetary savings in cover soil between milled and unprocessed refuse, two Madison landfills were compared. The first was the Olin Avenue site which was completely converted to a milled refuse landfill in mid-1971 and thus did not use daily cover. The other site was the Truax landfill for unprocessed refuse. The Truax site operates under strict sanitary landfill procedures and therefore uses considerable amounts of cover material. For this comparison it was assumed that the cover material used at Truax is obtained at no cost for the material, although this is not always the case. Costs for excavating and hauling the cover are included, however. The Truax operation handled about twice the volume of material as the Olin Avenue site during the period of record, January through June 1972 (Table 17).

The table reveals that Madison expended three times the amount of money, on a per-ton basis, to operate an unprocessed refuse landfill as it spends to operate a milled refuse landfill. This substantially higher cost of a conventional landfill operation as experienced in Madison is partly due to the handling of cover materials.

THE ECONOMICS OF MILLING

Landfilling

In the preceding section, it was stated that the operating cost of landfilling milled refuse amounted to $0.988 per ton for the period of January through June 1972. During this period, Madison spent $23,043 while landfilling 23,317 tons of milled refuse at the Olin Avenue site. This does not include charges for land, site preparation or final covering.

By far the greatest cost of the Olin Avenue landfill operation was labor. The site is manned by one full-time compactor operator who works a 7:30 a.m. to 4:00 p.m. shift. The operator averages 6 hours on the fill and 2 hours on maintenance of landfill equipment.

During the 6 month evaluation period, no difficulties were encountered handling the average daily load of 180 tons. It is believed, in fact, that an average of 500 tons per day could be handled routinely with no increase in men or machinery at the landfill.

Another labor expenditure was for cleanup of the area. Cleanup consists of picking up paper, cutting grass, etc. This chore averaged 184 man-hours per month, with another 2 hours per day for supervision.

An auxiliary operator spent 32 hours on the site during the entire 6 months on road repair.

Permanent equipment at the Olin Avenue site consisted of a Steel Wheel Compactor, which was operated between 5 and 7 hours per day. The city garage sets an hourly rate of $6.25 per hour for use of the equipment including amortization.

Stone and oil are used on access roads to the site. The stone allows good wet weather operation. The road oil keeps dust down in the summer dry periods.

Table 18 presents the actual costs of operating the Olin Avenue site during the first six months of 1972.

Table 17

Cost Incurred in Landfilling Milled and Unprocessed Refuse (January 1 - June 30, 1972)

Cost Item	Olin $/ton** Milled Refuse	Truax $/ton*** Unprocessed Refuse
WAGES*		
Compaction	0.310	0.449
Supervision	0.090	0.229
Caretakers	0.270	0.374
Paper pickup	none	0.222
Loading (cover)	none	0.182
Hauling (cover)	none	0.335
Road repair	0.010	0.010
Scale operator	none	0.121
SUBTOTAL	0.680	1.922
EQUIPMENT		
Compaction	0.206	0.449
Loading (cover)	none	0.209
Hauling (cover)	none	0.211
Paper pickup	0.020	0.015
Road repair	0.010	0.008
Misc. maintenance	none	0.076
Amortization	0.035	0.105
SUBTOTAL	0.271	1.073
MATERIALS - AREA IMPROVEMENT		
Stone	0.019	none
Road oil	0.018	none
SUBTOTAL	0.037	0.000
TOTAL	0.988	2.995

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*Includes all fringe benefits

**23,317 tons

***48,660 tons landfill

TABLE 18
Landfill Costs Using Milled Uncovered Refuse
(January 1 - June 30, 1972)

	Cost
WAGES*	
Compaction	$ 7,112
Supervision	2,413
Cleanup	6,518
Auxiliary Operator	221
SUBTOTAL	$15,994
EQUIPMENT	
Operation (Landfill Compactor Only)	$ 3,859
Auxiliary (Road Repair)	310
Amortization (Landfill Compactor Only)	2,025
SUBTOTAL	$ 6,194
MATERIALS - AREA IMPROVEMENT	
Stone	$ 435
Road Oil	420
SUBTOTAL	$ 855
TOTAL	$23,043

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*Includes all fringe benefits

Milling Costs

At Madison, there has been a considerable savings in landfill costs by using milled refuse without daily cover; however, the additional costs of the milling process itself must obviously be added to the landfilling cost to indicate the total cost of refuse disposal by the milling method. The following sections will investigate these costs and conclude with cost-per-ton projections which are reasonable for operations like the one at Madison.

Gondard System:

Cost data for the Gondard system are for the third year of the demonstration project, from June 1968 through May 1969, by which time the Gondard operations were refined. Although it is proper to report the costs incurred in the Madison plant, one must be cautioned about applying these costs to other installations because this project began as a pilot plant demonstration whose operation is probably more expensive than that of future plants. More importantly, one must recognize the regional variations in labor, power costs, heating costs, and depreciation methods. Inflation during the years since this study was undertaken must also be considered.

Furthermore, the unit costs in Table 19 is higher than would be the case for a larger and differently designed plant because:

1) Refuse was not conveyed to the mill as fast as the mill could grind;

2) A similar plant without extensive foundations and extra conveyors would be less costly;

3) Adaptation and improvements can still be made in haul-away operation.

As in other sections of this report, land costs are not included, because in most instances they are a negligible part of the total cost and vary too greatly from area to area to be meaningful. As an example, the Olin Avenue site was purchased at $1,000 per acre; similar land in the area is now selling for $5,000 to $10,000 per acre.

The costs per ton are calculated by dividing the annual cost by the annual tonnage. The annual tonnage figures are projected by using the overall Gondard production rate, the average number of working hours per day, and the number of working hours per week.

Table 19 lists the cost per ton for each of the major cost categories and for three grate sizes.

TABLE 19

UNADJUSTED COST DATA FOR GONDARD MILL
(JUNE 1968 THROUGH MAY 1969)

Cost Item	Annual Cost	Grate Size		
		3-1/2 Inch	5 Inch	6-1/4 Inch
		Annual Tonnage		
		10,750	11,500	12,050
Labor	$39,800	$3.70	$3.46	$3.30
Amortization	$32,200	$2.99	$2.80	$2.67
Power	variable	.34	.30	.30
Lighting	$ 2,300	.21	.20	.19
Water	$ 200	.02	.02	.02
Gas-heat	$ 1,200	.11	.10	.10
Hammer Wear	$1,600-1,710	.16	.15	.14
Mill Maintenance	$850-950	.08	.08	.08
Small Equipment	$ 800	.07	.07	.07
General Supplies	$ 1,100	.10	.10	.09
Front End Loader Operation	$ 500	.05	.04	.04
Transportation to Landfill*	$ 3,250	.30	.28	.27
Other	$ 1,700	.16	.15	.14
TOTAL		$8.29/ton	$7.75/ton	$7.41/ton

*Based on round trip of less than 1/2 mile

The average hourly wage for the three plant workers together during the evaluation period was $19.15, including all fringe benefits and overtime. Yearly labor cost is obtained by multiplying $19.15 by the number of working hours in a year (2080). This yields $39,830 per year for labor costs. To get labor cost per ton, this figure was divided by projected annual tonnage of 11,500 tons.

The annual cost of amortization was calculated by assuming machinery life and interest rates depending on source of funds. Table 20 lists data used to arrive at the annual amortization figure of $32,100.

The experimental periods did not exactly coincide with the utility companies' billing periods. It was therefore necessary to project power consumption to a monthly basis in order to determine equivalent monthly costs. The costs of power ranging from $0.34 to $0.30 per ton are the weighted averages during the times that the three grate sizes were used.

Computation of other costs was straightforward and needs no further explanation.

Tollemache System:

Two experimental runs using only the Tollemache mill were undertaken in the summer of 1970 and winter of 1971. During both of these runs, extensive cost data were collected on labor, power, repairs, replacements, etc. Thus, a comparison is possible between summer and winter operations of the same plant and equipment. To make the comparison equitable, changes in wages and other increases in cost between the two runs must be considered. Therefore, actual and adjusted costs will be presented for the data obtained during 1970, with adjusted cost being computed using the wages and prices in effect during the 1971 test.

Cost of the milling operation (excluding landfilling) is best presented in two general categories: that of milling, including conveyance of the unprocessed and milled material; and that of transportation to the final disposal site, including the stationary packer and hauling equipment.

Table 21 contains an extensive breakdown of the costs incurred during the two test periods on a per-ton basis. Affecting these figures are such uncontrollable factors as the average moisture content of the refuse being processed. Therefore the costs stated here can be viewed only as an indicator of what was experienced at one installation and as such they cannot be expected to be generally applicable to other locations.

An analysis of Table 21 indicates that on an adjusted basis the cost per ton for period 1, summer 1970, is about $0.43 less than period 2, winter 1971. There are two prime factors contributing to this. First is the fact that on the average fewer tons were milled per day during period 2; thus, relatively stable or fixed costs such as amortization increased on a per-ton basis. The decrease in average milled tons per day is due to seasonal variations in refuse quantities and moisture content. Also during period 2 gas and lighting costs increased due to changed weather conditions.

TABLE 20

DATA USED FOR COMPUTING AMORTIZATION OF ORIGINAL GONDARD INSTALLATION

Cost Item	Original Cost	Estimated Life-Years	Interest Rate	Salvage Value	Annual Cost
Building	$133,100	20	5.8	$4,000	$11,300
Grinder and Conveyors	126,700	15	5.8	4,000	12,700
Scale	6,900	20	7.0	1,000	600
Front End Loader	15,400	8	7.0	3,000	2,300
Packer Trucks (2)	38,000	10	7.0	3,000	5,200
	Total Annual Cost - Amortization				$32,100

TABLE 21

TOLLEMACHE MILLING COSTS

	Test Period #1*		Test Period #2*
	$/Ton	Adjusted $/Ton	$/Ton
Labor***	$2.395	$2.758	$2.577
Amortization	1.134	1.134	1.327
Hammers & Shafts	0.137	0.137	0.206
Power	0.245	0.284	0.351
Welding Rod	0.033	0.033	0.031
Plant Supplies	0.029	0.029	0.042
Front End Loader Maintenance	0.055	0.068	0.079
Gas - Heat	0.000	0.000	0.154
Lighting	0.052	0.059	0.105
Water & Sewer	0.001	0.002	0.006
Contracted Repairs	0.011	0.013	0.040
Replacement Parts	0.038	0.045	0.074
TOTAL	$4.130	$4.562	$4.992

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* 14 wks. - July 6 - October 9, 1970, 5318 tons milled, average - 77 tons/day and 5.3 hrs. machine time/day

** 8 wks. - February 4 - March 31, 1971, 2624 tons milled, average - 66 tons/day and 5.1 hrs. machine time/day

*** Includes all fringe benefits

The average overall adjusted cost per ton of approximately $4.80 can be misleading. It must be remembered that this figure has been derived from experimental runs. At the time of the tests the plant was only operating at three-fourths of its rated capacity. At full capacity the plant could average 90 to 100 tons/day as compared to the 65 to 75 experienced during the tests. This would mean that fixed costs, labor and amortization, would be reduced by nearly 27 percent over the tabulated cost per ton, and the overall cost would be reduced by 23 percent to an average of $3.70/ton.

Table 22 contains the detailed breakdown of costs for the stationary packer and transportation to the landfill on a per-ton basis for test periods 1 and 2. The actual cost as well as the adjusted cost per ton are presented for period 1 as in Table 21. Again, it is felt that transportation costs experienced at Madison during this evaluation are not indicative of transportation costs that would be expected at other localities under different conditions. Thus, these costs are presented separately to stress tht they apply to Madison's operation only.

The computations of costs during the Tollemache evaluation were made similarly to those in the Gondard economics section. However, several differences should be noted. First, the average total hourly wage, including fringe benefits and overtime, for the three plant personnel had risen from $19.15 to $20.39. Also, amortization figures were somewhat different, as shown in Tables 23 and 24.

Two-Mill, Two-Shift Operation:

Extensive cost data on all plant functions were collected during the first 6 months of 1972. As with the Tollemache system, these data will be presented in two parts - costs of milling and costs of compaction and final transportation.

Again, it is important to stress that the figures presented here are strictly applicable only to Madison's operation. This qualification is especially important in this section, in which two vastly different mills are being discussed.

The total cost of the 6-month run will be reported first. Table 25 gives a detailed breakdown of expenditures and costs per ton for the period of record. Total tons milled during that period were 23,317.

The total 6-month expenditure for mill operation was $91,000, or $3.90 per ton. Notice that labor and depreciation account for $2.75 per ton, or 71 percent of that total. Thus it is imperative for efficient operation that the maximum tonnage of refuse be milled during the 16-hour working day. If plant production could be increased from the current rate of 46,000 tons per year to a feasible 60,000 tons per year, the per-ton cost of milling could be reduced 15 percent to approximately $3.29 per ton.

TABLE 22

STATIONARY PACKER AND HAUL COSTS DURING TOLLEMACHE EVALUATION

	Test Period #1*		Test Period #2**
	$/Ton	Adjusted $/Ton	$/Ton
Amortization	$0.448	$0.448	$0.524
Labor (Driver)***	0.120	0.137	0.147
Power	0.016	0.019	0.023
Tractor & Trailer Maintenance	0.018	0.027	0.017
Packer Maintenance	0.010	0.012	0.012
TOTAL	$0.612	$0.643	$0.723

* 14 wks. in length - July 6 - October 9, 1970, 5318 tons milled, average - 77 tons/day and 5.3 hrs. machine time/day

** 8 wks. in length - February 4 - March 31, 1971, 2624 tons milled, average - 66 tons/day and 5.1 hrs. machine time/day

*** Includes all fringe benefits

TABLE 23

AMORTIZATION DATA FOR TOLLEMACHE MILLING SYSTEM

Item	Original Cost	Effective Life (Yrs.)	Interest Rate	Salvage Value	Annual Cost
Building and Foundation	$133,188	20	5.9%	$4,000	$11,390
Tollemache Mill And Conveyors	87,600	15	5.9%	4,000	8,640
Scale	5,916	20	6.5%	1,000	660
Front-End Loader	15,400	12	6.5%	3,000	1,700
TOTAL					$22,390*

* The total annual amortization cost of $22,390 can be proportioned to the 14 week and 8 week evaluation periods on a straight line basis. Amortization for the 14 week evaluation is 14/52 ($22,390) = $6,034 and for the 8 week period 8/52 ($22,390) = $3,448

TABLE 24

AMORTIZATION DATA FOR STATIONARY COMPACTOR AND FINAL TRANSPORTATION SYSTEM

Item	Original Cost	Effective Life (Yrs.)	Interest Rate	Salvage Value	Annual Cost
Stationary Compactor and Hopper	$ 19,150	15	6.5%	$1,000	$2,000
Two Trailers	33,000	12	6.5%	1,500	3,960
One Tractor	13,625	15	6.5%	1,500	1,390
Building Addition	16,801	20	6.5%	1,000	1,500
TOTAL					$8,850

TABLE 25

MILLING COSTS FOR TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Total Cost	Cost/Ton*
Labor	$44,684	$1.912
Amortization	19,570	0.838
Replacement Parts	8,097	0.346
Power	4,382	0.188
Hammers and Shafts	3,786	0.162
Heat - Gas	2,391	0.102
Supplies	2,196	0.094
Lighting	2,023	0.087
Front-End Loader Maintenance	1,653	0.071
Welding Rod	1,128	0.048
Contracted Repairs	1,047	0.045
Water and Sewer	44	0.002
TOTALS	$91,001	$3.895

* Based on 23,317 tons milled

The final figure of $3.90 per ton as presented in Table 25 represents a sizable reduction from the earlier stated costs for experimental runs of both the Gondard and Tollemache Systems separately. The figure is 48 percent lower than that actually experienced during the Gondard evaluations of 1968 and 1969. It is also 19 percent lower than the average figure obtained during the Tollemache evaluations of 1970 and 1971. The reduction is the result of better supervision and the 125 percent average daily increase in tonnages milled over that of the single-shift operations.

Total milling labor costs as charged to the plant during the 6 month of record are shown in Table 26.

The average total hourly wage for the three regular plant personnel needed for each shift is now $20.98. The plant supervisor's hourly wage is $6.25. Labor rates are based on job classification and length of service with the city.

A breakdown of labor costs into three main categories is given in Table 27. No differentiation is made between times devoted to the Gondard or Tollemache system individually.

The data indicate that nearly 73 percent of the total labor cost, not including supervision, is a result of mill operations, while only 15 percent and 12 percent is the result of repair and hammer maintenance, respectively.

Based on data from the Gondard and Tollemache systems, separately, the total amortization for the 6-month period was $19,570. On a per-ton basis the figure is $0.838.

Power costs for the two mills combined are presented in Table 28. Table 29 contains power cost data for the mill accessories.

In both tables the demand cost is constant each month, and in the case of the mills themselves, the demand charge is more than the energy used. This is an important factor in the overall power cost, as an increase in tonnage milled will decrease the total cost per ton. For example, during the Tollemache runs, power averaged $0.24 per ton at an average rate of 70 tons of refuse milled per day. Power costs for the Gondard runs averaged about $0.28 per ton back in 1968, at much lower rates, for an average of 46 tons of refuse milled per day. During 1972 the combined mill operation consumed power at the cost of $0.168 per ton, which represents a 53 percent reduction over the single-mill operation. The reason for the decrease is that 187 tons of refuse were processed per day in 1972.

Lighting and other small services are supplied by 220-volt service. Table 30 contains monthly 220-volt service costs and the amounts of electricity used.

The plant is heated by radiant natural gas heaters. Table 31 contains a monthly breakdown of heating costs. The total expenditure reflects 3 months of winter heating bills and 3 months of much lower spring bills. Past experience has shown that heating costs have gone almost to zero from June through September.

TABLE 26

LABOR COSTS - TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Actual Man Hours	Cost*	Cost/Ton**
Plant Personnel	5456	$38,180	$1.634
Supervision	1040	6,504	0.278
TOTAL	6500	$44,684	$1.912

* Includes all fringe benefits
** Based on 23,317 tons milled

TABLE 27

BREAKDOWN OF LABOR COSTS - TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Man-Hours			
	Total	Per Week	Cost*	Cost/Ton**
Mill Operation	3969	152.8	$27,754	$1.188
Repair Maintenance	850	32.7	5,944	0.254
Hammer Maintenance	641	24.7	4,482	0.192
SUBTOTAL	5460	210.0	$38,180	$1,634
Supervision	1040	40.0	6,504	0.278
TOTAL	6500	250.0	$44,684	$1.912

* Includes all fringe benefits
** Based on 23,317 tons milled

TABLE 28

POWER COSTS, MILLS, TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Demand Cost	Energy Cost	Total Cost	Cost/Ton*
January	$341	$257	$598	$0.225
February	341	311	652	0.195
March	341	332	673	0.196
April	341	329	670	0.158
May	341	330	671	0.131
June	341	321	662	0.146
OVERALL	$2046	$1880	$3926	$0.168

* Based on 23,317 tons milled

TABLE 29

POWER COSTS, MILL ACCESSORIES, TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Demand Cost	Energy Cost	Total Cost	Cost/Ton*
January	$ 19	$ 47	$ 66	$0.025
February	19	56	75	0.023
March	19	60	79	0.023
April	19	60	79	0.019
May	19	61	80	0.015
June	19	58	77	0.017
OVERALL	$114	$342	$456	$0.020

* Based on 23,317 tons milled

TABLE 30

LIGHTING COSTS, TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Demand (kw)	Energy (KWH)	Demand Cost	Energy Cost	Total Cost	Cost/Ton*
January	38.6	18,788	$ 58	$ 319	$ 377	$0.14
February	40.0	17,088	61	293	354	0.106
March	40.0	19,286	61	326	387	0.113
April	40.0	14,734	61	258	319	0.075
May	40.0	12,772	61	228	289	0.056
June	40.0	13,294	61	236	297	0.066
OVERALL			$363	$1660	$2023	$0.087

* Based on 23,317 tons milled

TABLE 31

PLANT HEATING COSTS, TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Usage 100 Cu. Ft. Gas	Cost	Cost/Ton*
January	8,679	$ 823	$0.309
February	8,297	788	0.262
March	5,124	468	0.136
April	1,983	194	0.046
May	618	63	0.012
June	540	55	0.012
OVERALL		$2391	$0.102

* Based on 23,317 tons milled

Total water usage equaled 6510 cu. ft. The cost of this water equaled $21.00. Sewer charges are 140 percent of the total water cost. Thus the water and sewer bill for 6 months equalled $44.45, or $0.002 per ton.

Items such as hammers, hammer shafts, and welding rods constitute supplies used in the hammer maintenance program. Table 32 contains all pertinent data in respect to the numbers of each item used and the resultant expenditure. Hammer maintenance supplies constitute the fourth largest expense in plant operations.

As seen in Table 25, the cost of replacement parts was over $8,000 and is therefore the third most expensive item on the list of plant expenses. Parts replaced during the period of record were mill grates (Gondard) and wear plates (Tollemache) as well as conveyor belting - all of which are very expensive items. A set of Tollemache liners, which lasts approximately 6 months, costs nearly $1,300. Gondard grates, also lasting 6 months, cost nearly $800 per set. Other parts such as small motors, conveyor slats, and bearings, make up the remainder of the expenditure in this area.

Other expenses included miscellaneous supplies, contracted repairs, and front-end loader maintenance. Supplies consisted of janitorial requirements, office materials, grease and oils, etc. The total expenditures for supplies, $2,196, is almost $0.10 per ton. Contracted repairs include all labor and material charges for repairs made by outside agencies. The total cost, $1,047, is less than $0.05 per ton. Front-end loader maintenance is dependent on the hours of vehicle use. The city garage charges $4.27 per hour of use to cover vehicle maintenance such as oil, minor repairs, grease, etc.

Expenses for compaction and hauling include labor, depreciation, power, and equipment maintenance. Not included are minor expenses due to heat, lighting, and water which are grouped under milling costs. Table 33 gives a complete listing of all expenses attributed to final handling of the milled material, excluding landfilling costs.

Labor expenses, as was the case with milling costs, constitute the largest expenditure for compaction and hauling. A total of 780 hours, or 30 man hours per week, was spent in transporting milled material to the landfill (round trip is less than 1/2 mile). Vehicle maintenance is computed on a per-mile charge. Tractors are charged at a rate of $0.20 per mile and transfer trailers at the rate of $0.25 per mile. The charges cover all fuel, oils, grease, and minor repairs.

Table 33 indicates that the total power cost is almost insignificant at $0.014 per ton. The stationary compactor maintenance at $0.032 per ton consists of labor and parts for all repairs to the compactor. As the figures show, the compactor is not prone to breakdowns.

TABLE 32

SUPPLY COSTS, HAMMER MAINTENANCE, TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Used	Unit Cost	Total Cost	Cost/Ton*
Hammers	1000	$ 3.27	$3,270	$0.140
Shafts	43	12.00	516	0.022
Welding Rod (lbs.)	600	1.88	1,128	0.048
OVERALL			$4,914	$0.210

*Based on 23,317 tons milled

TABLE 33

STATIONARY COMPACTION AND HAUL COSTS, TWO-MILL, TWO-SHIFT OPERATION (JANUARY THROUGH JUNE 1972)

	Cost	Cost/Ton*
Labor	$ 5,216	$0.223
Amortization	4,380	0.188
Compactor Maintenance	753	0.032
Haul-Vehicle Maintenance	597	0.025
Power	334	0.014
OVERALL	$11,280	$0.482

*Based on 23,317 tons milled

Cost Projections

Based on the extensive cost data on operations at the Madison Refuse Reduction plant, several projections have been made on the costs of various milling systems employing the Tollemache mill. The estimates take into account one through four mills operated either one or two milling shifts per day and an additional shift for maintenance.

It is important to realize that, while the projections are thought to be accurate, they apply strictly only to Madison. Wage rates, power and utility rates, depreciation, etc. are all based on mid-1972 costs as experienced in Madison, Wisconsin. To arrive at projected costs for similar operations at other localities, it will be necessary to make an economic study using appropriate base rates.

It was assumed in these projections that each Tollemache mill will operate an average of 7 hours per shift at a rate of 14 tons per hour. It was also assumed that the plant will operate 245 days (or 49 weeks) per year, with 3 weeks for repairs. Each plant will include a minimum of one mill, one feed conveyor, two transfer trailers, and one tractor. Two mill plants will have two mills and feed conveyors, but will otherwise be similar to a one mill installation. Plants with three or four mills will have two discharge conveyors, two stationary compactors, four or five trailers, and two tractors. In addition to the one or two milling shifts is an additional maintenance shift. The maintenance shift duties involve mill maintenance, plant clean up and maintenance, and machine repair work.

Under these conditions, each mill will produce approximately 100 tons per day, or 24,500 tons per year. Daily and annual tonnages for combinations of mills and shifts are tabulated in Table 34.

A cost analysis of the various plant sizes on a one and two shift milling operation resulted in projected milling, transfer, and landfilling costs per ton as shown in Table 35. A detailed cost analysis is provided in Appendix A of this report.

Thus, if a municipality generates 196,000 tons of millable refuse per year, this refuse could be milled and landfilled for a cost of $2.75 per ton using four Tollemache mills for two shifts per day. This corresponds to Madison's present costs of $4.88 per ton for milling and landfilling refuse and $3.00 per ton for landfilling unprocessed refuse.

It is to be stressed that milling is but an alternative method which can be used in conjunction with landfill. It is not meant as a replacement for landfill. Instead, its characteristics may enable a higher set of operational standards to be followed at similar or slightly higher costs than standard sanitary landfilling.

TABLE 34

Production Estimates
(For one and two shifts, and one to four mills)

	Number of Mills			
	1	2	3	4
One Shift				
Daily tons	100	200	300	400
Annual tons	24,500	49,000	73,500	98,000
Two Shifts				
Daily tons	200	400	600	800
Annual tons	49,000	98,000	147,000	196,000

TABLE 35

Annual Average Costs per Ton for Milling, Hauling, and Landfilling Refuse

	Number of Mills			
	1	2	3	4
One Shift				
Annual tonnage	24,500	49,000	73,500	98,000
Milling, stationary compactor, and haul costs/ton*	5.27	3.74	3.48	3.33
Millfilling costs/ton	1.43	0.75	0.73	0.57
TOTAL costs/ton	6.34	4.59	4.21	3.90
Two Shifts				
Annual tonnage	49,000	98,000	147,000	196,000
Milling, stationary compactor, and haul costs/ton*	3.75	2.70	2.52	2.30
Millfilling costs/ton	0.75	0.50	0.57	0.45
TOTAL costs/ton	4.50	3.20	3.09	2.75

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*Cost includes amortization, labor, operation, and milled refuse haul to landfill less than ½ mile away. Land cost excluded.

TRENDS AND DEVELOPMENTS

Before the Madison milling project began in 1967, the only milling of solid waste in the United States was for the production of compost. Since Madison's project was initiated, most of these composting facilities have been closed down for one reason or another, but a number of other milling facilities have been constructed and many more are in the planning or construction stages. The facilities that have been constructed or that are being planned are for the purposes of:

1. Milling refuse for baling in a continuous baler - San Diego, California.
2. Milling refuse for energy recovery by burning it in a conventional coal or gas fired power plant - St. Louis, Missouri.
3. Milling refuse for energy recovery in new types of municipal incinerators in which most of the burning takes place in air suspension - Hamilton, Ontario, Canada.
4. Milling refuse for landfill disposal - Pompano Beach, Florida; Milford, Connecticut; Vancouver, Washington; etc.
5. Milling refuse for resource recovery - at the present time, March 1973, the City of Madison is one of the few facilities known to be magnetically separating the ferrous metal from milled refuse. A number of future plants will magnetically separate ferrous metal and will also attempt more advanced schemes of resource recovery.

The original application for the Madison demonstration project was entitled, "Solid Waste Reduction/Salvage Plant". It was envisioned that marketable material could be picked from the solid waste feed belt by hand and marketed through local salvage dealers. While time has shown that this idea was rather naive in terms of recycling, it does illustrate that the concept of material recovery from solid waste was one of the motivating factors for the Madison project.

Since then, the City of Madison has entered into a separation-at-the-source newsprint recovery project; a cooperative project with the Continental Can Company for magnetic separation and marketing of ferrous metal from the milled refuse; and a log recycling project in cooperation with Urban Wood Fiber, Inc. A cooperative agreement with the Forest Products Laboratory, U.S. Department of Agriculture, for recycling of wood fiber has resulted in work on wood fiber separation. Following is a more detailed description of these projects.

In 1967, the National Committee for Paper Stock Conservation approached the City of Madison with a proposal that the Committee and the City of Madison work together on a project to collect newsprint separated at the source. Since early contacts with local secondary material dealers had indicated that any paper that had been in a packer truck would not meet existing paper specifications, the City of Madison expressed interest in the recycling project proposed by the Committee, In the fall of 1968, the City of Madison entered into a pilot project on the east side of the community which in 1970 was extended to the west side of Madison. The newspapers are bundled separately by cooperating citizens, placed at curbside along with the remainder of the solid wastes, and placed by the collection crews on specially built racks under the packer bodies. In 1972 approximately 2,800 tons of newsprint were collected; this amounted to about 1.5 percent of the total amount of solid waste collected and brought to City of Madison disposal sites.

A study of the realities of recycling by the City of Madison led to the conclusion that probably only newsprint meets the criteria for a successful separation-at-the-source program. Newsprint is easily identified by the home owner, available in large quantities, and fairly easily marketable. When the newsprint project was beginning, a new de-inking mill was going on line at Alsip, Illinois and this created a new demand in the Midwest for newsprint.

A study of further recovery of wood fiber has led to the conclusion that mechanical methods are necessary for large-scale recovery. Dialogue with the Forest Products Laboratory in Madison led to a cooperative agreement in 1970 between that institution and the City of Madison to cooperate on fiber recovery. Madison's main role in this project was to provide working space at the Refuse Reduction Plant and to supply milled refuse for the Forest Products Laboratory projects.

The pilot separation facility established by the Forest Products Laboratory at the Olin Avenue Refuse Reduction Plant is a flexible dry-separation system. The system is designed to use air currents to separate light materials (paper and sheet plastics) from heavy materials and to separate the paper into several types. Equipment includes two fans, two cyclone units, an air classifier, a dry screen, and conveyor and collector bins. All separation equipment in the pilot facility is available commercially. Specific units were acquired solely on the basis of availability and their application to the pilot scale. Other commercial equipment may be equally suitable for the same purposes.

The first fiber recovery experiments began in the fall of 1971. Since then, the Forest Products Laboratory has used wood fiber to make paper and building products out of the material in sufficient quantity and size to run standard tests on the quality of materials from urban waste. Efforts are currently underway to obtain large enough samples of the wood fiber to run production-scale tests of various products.

In September 1971 the City of Madison entered into an agreement with the Continental Can Company, Inc., which granted that company 5 years of salvage rights of the ferrous metals and alloys removed from milled refuse. Under terms of the agreement, the Continental Can Company installed a magnetic separator, provided the trucks to haul the material away, and developed the markets. They also paid the City of Madison 10 percent of any profits. Perfecting the mechanics of magnetic separation has taken approximately a year and has required some developmental work. A new magnetic separation unit has been installed on the basis of the experience gathered with the first unit. The new unit is obtaining approximately 95 percent of the ferrous metals, and during a run in February 1973, 10 percent by weight was removed as ferrous metals from approximately 20,000 lbs. of solid waste.

After lengthy negotiations with Urban Wood Fiber, Inc., the City of Madison has obtained an outlet for market-sized logs from municipal and private tree clearing operations in the City of Madison. This operation was a direct spin-off of attempts to develop a milling system for trees and logs generated in the City of Madison.

Another study undertaken through the City of Madison milling project has been work by Professor Norman Braton of the University of Wisconsin-Madison Mechanical Engineering Department on developing techniques for shredding frozen tires. The tires are first frozen in liquid nitrogen and then dropped into a hammermill. The frozen rubber is quickly and easily separated from the remainder of the tire carcass. Professor Braton proposes to develop equipment on a railroad car which could be shipped from place to place to freeze and fragment tires, thus producing marketable rubber.

There are over one hundred plants in the United Kingdom and on the European continent which are milling refuse for landfill disposal without daily cover. Some of these facilities have been in operation for 20 years. A result of the Madison project has been the construction and operation of a number of facilities in the continental United States for milling refuse for landfill disposal. In addition, there are also on the drawing boards or under construction many more of such facilities. While only time will determine the ultimate success or failure of the milling approach, it is felt that milling is definitely assuming a significant role in the solid waste management field in the United States.

CONCLUSIONS

Among the conclusions of the demonstration milling project in Madison between 1967 and 1972 are the following:

1. As operated at Madison, the Gondard hammermill has a capacity of 9 tons per hour with a 5-inch grate, and the Tollemache hammermill has a capacity of 14 tons per hour with a 34-hammer pattern. The grate size and hammer pattern were chosen to grind refuse as coarsely as possible without producing problems of blowing litter at the landfill and without leaving food wastes accessible to vectors. (On a dry-weight basis, between 80 and 90 percent of the particles produced by both mills pass through a 2-inch screen.) Evaluations of the two mills separately showed that the Gondard mill uses nearly as much electrical energy as the Tollemache mill while producing only about 60 percent as much milled product as the Tollemache.

2. Aside from some minor problems with the mills themselves, most of the early operational problems were associated with conveying refuse to the mills and carrying milled refuse to the landfill. The steeply inclined feed conveyor and the stationary compactor with a 75-cu. yd. transfer vehicle used with the Tollemache mill have greatly increased the ability of the Madison plant to handle unprocessed and milled refuse on a production basis.

3. Residential and light commercial refuse as collected at Madison can be milled in either type of hammermill without extensive presorting, with minimal hand-picking of unmillables, and with negligible downtime due to mill stoppage.

4. Milled refuse has been left in a landfill without cover for up to 6 years, and no complaints have been received about odors, unsightliness, blowing litter, rodents, or insects. Public acceptance of the milling plant and the landfill has been unusually good.

5. Experience with milled refuse without daily cover indicates that the quality of operation at this type of landfill is superior to sanitary landfill operations at Madison with respect to travel over the fill and at the face of the fill, dust, tracking of trucks on highways, appearance during operating hours and maintaining a uniformly high level of operation during cold and wet weather. Fully loaded trucks weighing nearly 73,000 lbs. can drive on milled refuse in inclement weather. Also, tire problems have not been caused by travel on uncovered milled refuse.

6. Experience and specific testing have shown that there is less fire hazard with milled than with unprocessed uncovered waste in a fill.

7. Rats are not able to survive on properly milled refuse containing up to 20 percent wet garbage on a wet-weight basis. Based on this finding and on observations of the landfill site, there is very little likelihood of rat infestation and survival in a properly operated milled refuse landfill.

8. Under optimum weather and moisture conditions, flies probably can breed in freshly milled refuse; however, once such refuse has aged several months, this ability is evidently lost. Tests with the Gondard mill showed that nearly all fly maggots passing through the mill during

normal operation were killed. Fly counts and operating experience at Madison indicate that there is no fly nuisance problem associated with milled refuse.

9. Compaction of cover soil, as well as production of methane and carbon dioxide by underlying refuse, created poor aeration conditions for tree roots and thus led to a high mortality of trees planted on milled and unprocessed refuse cells after 2 years. White ash and crab were the most successful of the tree varieties planted in that they developed effective lateral root systems in the densely compacted cover soil.

10. Actual refuse density of milled refuse on a wet-weight basis was found to be approximately 27 percent greater than the actual refuse density of unprocessed refuse given equal compaction. Under the same conditions, the effective refuse density of milled refuse was calculated to be nearly 35 percent greater than that of unprocessed refuse.

11. Leachate production occurs at a faster rate in milled **uncovered cells than in covered cells, milled or unprocessed. In the absence of cover, milled refuse develops a relatively mature degradation pattern** and thus lowers the organic pollution load leaving the refuse in leachate. Before a mature degradation condition develops in milled refuse, large quantities of organics in particular are leached from milled refuse.

12. The covered unprocessed refuse cells never produced organics at as high a rate as did the milled cells during initial stages of decomposition; however, the unprocessed cells continued to produce organics at a fairly consistent rate throughout the duration of the project. Thus, the milled refuse cells could be characterized as producing more leachate contaminants during initial stages of decomposition but less during later stages of decomposition than the unprocessed refuse cells.

13. A water budget analysis shows that in Madison, Wisconsin about 68 percent of incident precipitation on covered refuse in a landfill evaporates, while the remaining 32 percent is divided almost equally between runoff and infiltration (leachate). Virtually no runoff and slightly more evaporation occurs with uncovered milled refuse.

14. In the first evaluation of the Gondard mill with a 5-inch grate in mid-1968, a per-ton cost of $7.75 - including process and hauling costs but excluding landfilling costs - was experienced. When this figure was adjusted to exclude factors related solely to the experimental aspects of the operation, a comparable cost of $5.33 per ton emerged as a reasonable estimate for a production facility. During an evaluation of the Tollemache mill in the summer and fall of 1970, a cost of $4.13 per ton for milling and hauling (but not landfilling) was calculated. A winter evaluation early in 1971 yielded a cost per ton of $4.99. These two Tollemache figures are based

on the weight of refuse as received at the plant and include increased labor costs incurred during the second evaluation.

15. For a two-mill, two-shift operation during the first 6 months of 1972, a milling cost of $3.90 per ton was determined, based on 23,317 tons milled; another $0.48 per ton must be added to this figure to cover compaction and hauling less than 1/2 mile. The operating costs of landfilling for the first 6 months of 1972 in Madison were $0.99 per ton for milled refuse and $3.00 per ton for unprocessed refuse, excluding any land and development costs. During this period, regular sanitary landfills in Madison handled about twice as much material as did the milled refuse landfill.

16. Based on the findings of this study, a cost of $3.11 per ton of milled refuse was projected for a two-shift, two-Tollemache-mill operation. This figure includes milling, hauling less than 1/2 mile, and landfilling and assumes a continuous supply of millable refuse. The City of Madison will continue milling refuse at the Olin Avenue Milling Plant. In the Summer of 1973, the Olin Avenue Millfill operation will be completed. The City has recently acquired another landfill approximately nine miles from the milling plant. The milling plant will serve as a central processing and transfer station from which the milled refuse will be hauled to the new millfill facility.

APPENDIX A

COST PROJECTIONS FOR NEW MILLING PLANTS AND LANDFILLS

This segment of the report includes detailed data in respect to operating requirements and cost projections for a combination of one through four mills operated either one or two operating shifts with one maintenance shift. The estimates given in this portion of the report are based on data collected utilizing the Tollemache vertical shaft hammermill in Madison, Wisconsin. It is important to realize that the cost projections have been developed on the basis of costs at Madison. The wage rates, power and utility rates, depreciation, etc. are all based on 1972 Madison cost data. To arrive at projected costs for similar operations an economic study following the lines of that presented below may be made using the appropriate base rates as applied to the area being studied.

Basic Design Criteria

The following design criteria were used in plant design and eventual cost projections:

(1) Each mill will operate an average of 7 hours per shift at a rate of 14 tons per hour.

(2) The plant will operate 245 days or 49 weeks per year. Three weeks are allowed for repairs and breakdowns.

(3) The milling production day (one or two milling shifts) will be followed by an eight-hour maintenance shift.

(4) Each plant will have as many feed conveyors as mills. One and two mill plants will have one discharge conveyor and one stationary compactor.

(5) Plants containing 3 or 4 mills will have two discharge conveyors and two stationary compactors.

(6) Cost projections are primarily based on pilot plant and two shift studies conducted with the equipment mentioned in the text.

(7) All pertinent data as to wage rates, utility rates, depreciation, etc. are based on the evaluation data from Madison.

Annual Tonnage

Each Tollemache mill operating one shift will have a daily capacity of 14 tons/hour x 7 hours/day, or approximately 100 tons per day. The corresponding annual tonnage for one mill shift will be 100 tons/day x

245 days/year = 24,500 tons per year. Daily and annual tonnages for combinations of mills and shifts are listed in Table A-1.

TABLE A-1

Daily and Annual Tonnage Processed for Combinations of Mills and Shifts

	Number of Mills			
	1	2	3	4
One Shift				
Daily Tonnage	100	200	300	400
Annual Tonnage	24,500	49,000	73,500	98,000
Two Shifts				
Daily Tonnage	200	400	600	800
Annual Tonnage	49,000	98,000	147,000	196,000

Size of Plant

Experience has shown refuse quantities to vary throughout the year. Peak tonnage rates are about 1.5 times the average daily tonnage. Good plant design involves increasing available storage to allow for mill breakdowns, etc. A factor about 1.5 times the average daily tonnage through the plant is used to determine storage space. The maximum storage requirement then becomes 150 percent of the average daily tonnage processed on a one shift basis and is reduced to 125 percent of the daily tonnage processed on a two shift basis. The reduction in excess capacity is due to an increase in scale.

The maximum storage which must be provided is listed in Table A-2. The values in Table A-2 were determined by multiplying the daily tonnage in Table A-1 by 150 percent for plants operating one shift, and by 125 percent for plants operating two shifts.

TABLE A-2

Maximum Storage Requirements for Combinations of Mills and Shifts - Tons

	Number of Mills			
	1	2	3	4
One Shift	150	300	450	600
Two Shifts	250	500	750	1,000

Assuming a density of 400 pounds per cubic yard on the dumping floor, and an average stacked storage height of 8 feet, 0.53 ton can be stored per square yard of floor space, or 0.059 tons per square foot of floor space. The square footage of floor storage is computed by dividing the tonnages in Table A-2 by 0.059 ton per square foot.

TABLE A-3

Square Footage of Floor Storage Space Required For Combinations of Mills and Shifts

	Number of Mills 1	2	3	4
One Shift	2,500	5,000	7,500	10,000
Two Shifts	4,300	8,500	12,700	17,000

The total plant size including refuse storage space on the floor, conveyors and mills, and office is tabulated below. (A plant with three or four mills will be considered to be equipped with two discharge conveyors and two stationary compactors.)

TABLE A-4

Total Plant Size - Square Feet

	Number of Mills 1	2	3	4
One Shift				
Office & Workshop	1,000	1,000	1,500	1,500
Employee Facilities	300	300	500	500
Conveyor(s), Mill(s) and Compactor(s)	3,500	5,000	9,000	10,500
Floor Storage-Refuse	2,500	5,000	7,500	10,000
TOTAL	7,300	11,300	18,500	22,500
Two Shifts				
Office & Workshop	1,000	1,000	1,500	1,500
Employee Facilities	500	500	700	700
Conveyor(s), Mill(s) and Compactor(s)	3,500	5,000	9,000	10,500
Floor Storage-Refuse	4,300	8,500	12,700	17,000
TOTAL	8,800	15,000	23,900	29,700

The cost of foundations and building is computed by multiplying the total space requirements in Table A-4 by $20 per square foot. The entrance road and site grading is computed on the basis of 20 percent of the foundations and building construction costs.

TABLE A-5

Cost of Foundations, Buildings, Entrance, Roads, and Grounds
For Combinations of Mills and Shifts

		1	2	3	4
One Shift	- Foundations and Buildings	$146,000	$226,000	$370,000	$450,000
	- Entrance Roads and Grounds	29,200	45,200	74,200	90,000
	TOTAL	$175,200	$271,200	$444,200	$540,000
Two Shift	- Foundations and Buildings	$176,000	$300,000	$478,000	$594,000
	- Entrance, Roads and Grounds	35,200	60,000	95,600	11,900
	TOTAL	$211,200	$360,000	$573,600	$605,900

Labor Requirements and Costs

The number of men needed to man the combination of mills and shifts under consideration are shown in Table A-6 as are the annual costs of labor. Past experience at Madison has shown the need for proper supervision at all levels of plant operation; thus, one supervisor is required for each case shown. Also included are two maintenance men for one and two mill installations and three maintenance men for three and four mill installations. These men will work an 8-hour maintenance shift following each day's milling operation, whether one or two milling shifts are used.

Mill Maintenance - Annual Cost

(1) Hammers - 1100 tons/set at $106 per set

(2) Shafts - 500 tons/shaft at $12.00/shaft

(3) Wear Plates - 20,000 tons/set at $1600 per set

(4) General Maintenance:

Mill - replace bearings and rotor once every three years for one shift operation, $2,500 for each mill operating one shift, and 80 percent additional for second shift.

Conveyors - $600 for the feed conveyor, and $200 for each discharge conveyor for one mill operating one shift. The cost for the second shift will be an additional 80 percent.

(5) Welding Rods - 34 rods/set at $.50/rod; or $17.00 per set of hammers. 50 lbs./liner set at $1.60/lb.; or $80.00 per set of liners.

(6) Plant Supplies - $1,200 per one mill shift; $500 additional for each mill; 50 percent additional for second shift.

TABLE A-6

Annual Labor Requirements and Costs

			Number of Mills			
	Hourly Wage*	Annual Wage	1	2	3	4
One Shift						
Supervisor	$6.26**	$13,000	1	1	1	1
Reduction Plant Foreman-Operator	$8.02	$16,660	1	1	1	2
Reduction Plant Operator	$7.21	$14,990	1	2	2	3
Public Works Maintenance Man	$6.20	$12,890	2	2	3	3
Scale Man	$4.73	$ 9,840	-	-	1	1
Total			$ 70,430	$ 85,420	$108,150	$139,800
Two Shifts						
Supervisor	$6.26	$13,000	1	1	1	1
Reduction Plant Foreman	$8.02	$16,660	2	2	2	4
Reduction Plant Operator	$7.21	$14,990	2	3	4	4
Public Works Maintenance Man	$6.20	$12,890	2	2	3	3
Scale Man	$4.73	$ 9,840	-	1	2	2
Total			$102,080	$126,910	$164,630	$197,950

*Including 30 percent fringe benefits and estimated overtime.

**Other employees salary higher due to longevity pay program in City of Madison.

TABLE A-7

Annual Mill Maintenance Costs

	Number of Mills			
	1	2	3	4
One Shift				
(1) Hammers	$ 2,330	$ 4,660	$ 6,990	$ 9,320
(2) Shafts	580	1,160	1,740	2,320
(3) Wear Plates	1,600	3,860	5,760	7,680
(4) General Maintenance				
Mill(s)	2,500	5,000	7,500	10,000
Conveyor(s)	800	1,600	2,800	4,000
(5) Welding Rods	370	740	1,110	1,480
(6) Plant Supplies	1,200	1,700	2,200	2,700
Total	$ 8,580	$18,720	$28,100	$37,500
Two Shifts				
(1) Hammers	$ 4,660	$ 9,320	$13,980	$18,640
(2) Shafts	1,160	2,320	5,480	4,640
(3) Liners	3,868	7,680	11,520	15,360
(4) General Maintenance				
Mill(s)	4,500	9,000	13,500	18,000
Conveyor(s)	1,440	2,800	5,040	7,200
(5) Welding Rods	740	1,480	2,220	2,960
(6) Plant Supplies	1,800	2,550	3,300	4,050
Total	$18,160	$35,150	$53,040	$70,850

Power for Mills, Conveyors, and Stationary Compactor

(1) The maximum demand for each mill and conveyor system is 160 kw.

(2) The maximum demand for the compactor is 20 kw.

(3) The power consumption for each mill and conveyor system averages 8.8 KWH/ton.

(4) The power consumption for each compactor is 16 KWH/hour.

The monthly demand charge for one mill and conveyor system is:

$2.00 for the first 10 kw, $2.00 per kw for each of the next 90 kw, and $1.00 per kw up to the 160 kw required for a total of $242

The monthly demand charge for each additional mill and conveyor system is:

$1.00 x 160 kw = $160

The monthly demand charge for each compactor is:

$1.00/kw x 20 kw = $20

The power consumption for one mill and conveyor system operating one shift is 8.8 KWH/ton x 14 tons/hour = 123.2 KWH/hr. The monthly consumption then is 123.2 KWH/hour x 7 hours/day x 5 days/week x 4.0 weeks/month = 17,250 KWH/month. The monthly consumption cost for one mill operating one shift is: 0.026 x 500 KWH + $0.015 x 1000 KWH + $0.011 x 8500 KWH + $0.010 x 7,250 = $194. The monthly consumption for all additional mill-shifts is $0.010 x 17,250 KWH = $172. The monthly power consumption for each compactor working each shift is 16 KWH/hr x 7 hrs./shift day x 5 days/week x 4.0 weeks/month = 2,240 KWH/month. The corresponding monthly consumption cost for each compactor shift is $0.080 x 2,240 KWH = $22. The above listed power consumption costs are summarized as follows:

The monthly power consumption cost for the first mill-shift is $194.

The monthly power consumption for all additional mill-shifts is $172.

The monthly power consumption cost for all compactor-shifts is $22.

TABLE A-8

Annual Power Costs for Mill(s) Conveyor(s), and Compactors

		Number of Mills			
		1	2	3	4
One Shift					
Demand					
First Mill	$242	$ 242	$ 242	$ 242	$ 242
Each Addnl. Mill	160	-	160	320	480
Each Compactor	20	20	20	40	40
Power Consumption					
First Mill-Shift	194	194	194	194	194
Each Addnl. Mill-Shift	172	-	172	344	516
Each Compactor-Shift	22	22	22	44	44
Total Monthly Charge		$ 478	$ 810	$ 1,184	$ 1,516
Annual Charge		$5,736	$9,720	$14,208	$18,192
Two Shifts					
Demand	$242	$ 242	$ 242	$ 242	$ 242
Each Addnl. Mill	160	-	160	320	480
Each Compactor	20	20	20	40	40
Power Consumption					
First Mill-Shift	194	194	194	194	194
Each Addnl. Mill-Shift	172	172	516	860	1,204
Each Compactor-Shift	22	44	44	88	88
Total Monthly Charge		$ 672	$ 1,176	$ 1,744	$ 2,248
Annual Charge		$8,064	$14,112	$20,928	$26,976

Lighting

The consumption is to be proportioned on the basis of:

(1) The actual consumption in the reduction plant for one shift from July 1970 through December 1970, and for two shifts from January through June of 1972.

(2) The relative sizes of the buildings.

The original building used for a one-shift operation was 60 ft. x 100 ft. = 6,000 sq. ft. The expanded building used for the two-shift operation is approximately 13,000 sq. ft. The ratio of floor space for the projected plants, as listed in Table A-9 to 6,000 sq. ft. or 13,000 sq. ft. where applicable, is the relative size factor. The relative sizes are:

TABLE A-9

Relative Sizes of Buildings

	Number of Mills			
	1	2	3	4
One Shift	$\frac{7,300}{6,000} = 1.22$	$\frac{11,300}{6,000} = 1.88$	$\frac{18,500}{6,000} = 3.08$	$\frac{22,500}{6,000} = 3.75$
Two Shifts	$\frac{8,800}{13,000} = .68$	$\frac{15,000}{13,000} = 1.15$	$\frac{23,900}{13,000} = 1.84$	$\frac{29,700}{13,000} = 2.28$

Table A-10 shows the actual consumption for the existing plant per month studied, and the proportional usage based on relative building sizes, for one shift. Table A-11 contains the same information as related to a two-shift operation.

TABLE A-10

Actual and Proportioned Power Consumption (KWH)
For Lighting-One Shift

Month	Actual KWH Consumption	Number of Mills			
		1	2	3	4
July 1970	4,414	5,385	8,298	13,595	16,552
August 1970	4,104	5,007	7,715	12,640	15,390
September 1970	4,018	4,902	7,554	12,375	15,068
October 1970	5,860	7,149	11,017	18,048	21,975
November 1970*	5,900	7,198	9,109	18,172	22,125
December 1970*	5,400	6,588	10,152	16,632	20,250
Average		6,038	8,974	15,243	18,560

*Figures adjusted - due to construction

TABLE A-11

Actual and Proportional Power Consumption (KWH) For Lighting-Two Shifts

Month	Actual KWH Consumption	Number of Mills			
		1	2	3	4
January 1972	18,788	12,775	21,606	34,570	42,836
February 1972	17,088	11,620	19,651	31,442	38,960
March 1972	19,286	13,114	22,179	35,486	43,972
April 1972	14,734	10,019	16,944	27,110	33,593
May 1972	12,772	8,650	14,687	23,500	29,006
June 1972	13,294	9,040	15,288	24,460	30,310
Average		10,868	18,393	29,590	36,446

Based on the data given in Tables A-10 and A-11 a fairly good monthly average of lighting power consumption for a one and two-shift operation can be obtained. Table A-12 contains this average in relation to number of mills.

TABLE A-12

Average Monthly Power Consumption (KWH) For Lighting One and Two Shifts

	Number of Mills			
	1	2	3	4
One Shift	6,038	8,974	15,243	18,560
Two Shift	10,868	18,393	29,590	36,446

The demand charge would also be proportional to the size of the building, but would be nearly constant throughout the year because the charge is based on the high during the preceding 12 months. The maximum demand for the original one-shift plant was 20 kw and for the two-shift plant 40 kw. The maximum demand to be expected in any of the projected plants is calculated by multiplying 20 kw or 40 kw whichever is applicable by the relative building sizes as listed in Table A-9. The maximum demand is tabulated below.

TABLE A-13

Maximum Demand For Lighting - kw

	Number of Mills 1	2	3	4
One Shift	24	38	62	75
Two Shifts	27	46	74	91

The annual cost of lighting can be computed using the monthly average consumption (KWH) and maximum demand as shown in Tables A-12 and A-13 and the current utility rates. Table A-14 contains the summary of lighting costs.

TABLE A-14

Annual Cost of Lighting for Combinations Of Mills and Shifts

	Number of Mills 1	2	3	4
One Shift				
Demand	$ 120	$ 696	$1,272	$1,584
Consumption	936	1,320	2,148	2,592
Total	$1,056	$2,016	$3,420	$4,176
Two Shifts				
Demand	$ 432	$ 888	$1,560	$1,968
Consumption	1,572	2,568	4,044	4,944
Total	$2,004	$3,456	$5,604	$6,912

Gas Heat

The gas costs are computed in a similar manner as for lighting costs because consumption is dependent on building size. The actual consumption is to be proportioned on the basis of:

(1) the actual consumption in the reduction plant for one shift from July 1970 through December 1970, and for two shifts from January through June of 1972, and

(2) the relative sizes of buildings.

The relative building sizes have been previously computed and are shown in Table A-9. The actual gas consumption for the existing plant, and the proportioned usage based on relative building size are shown in the following two tables.

TABLE A-15

Actual and Proportioned Gas Consumption (Heat) - One Shift

Month	Actual Consumption (Cu.ft.x100)	Number of Mills 1	2	3	4
July 1970	0	0	0	0	0
August 1970	0	0	0	0	0
September 1970	30	37	56	92	112
October 1970	780	952	1,466	2,402	2,925
November 1970	3,420	4,173	6,430	10,533	12,825
December 1970	3,600	4,392	6,768	11,088	13,500
Average		1,590	2,450	4,020	4,890

The consumption for two shifts is listed in the following table. The proportioned consumption was obtained by multiplying the relative building size by actual consumption used in the expanded plant under two-shift operation.

TABLE A-16

Actual and Proportioned Gas Consumption (Heat) - Two Shifts

Month	Actual Consumption (Cu.ft.x100)	Number of Mills 1	2	3	4
January 1972	8,679	5,900	9,980	15,970	19,790
February 1972	8,297	5,640	9,540	15,270	18,920
March 1972	5,124	3,480	5,890	9,430	11,680
April 1972	1,983	1,350	2,280	3,650	4,520
May 1972	618	420	710	1,140	1,410
June 1972	540	370	620	990	1,230
Average		2,860	4,840	7,740	9,590

Since only 6 months of good gas consumption data for a one and two shift operation at Madison is available, only a rough estimate of gas costs can be calculated. This estimate is computed by doubling the total cost figure obtained from the proportioned consumption as presented in Tables A-15 and A-16. The estimate is valid because each six-month's term studied contains equal periods of warm and cold weather in relation to that period not studied. Table A-17 contains the projected yearly costs for gas as heat, based on natural gas rates in effect at the time of evaluation.

TABLE A-17

Annual Cost of Gas (Heat)
One and Two Shifts

	Number of Mills			
	1	2	3	4
One Shift	$1,746	$2,580	$4,104	$4,950
Two Shifts	$2,976	$4,902	$7,722	$9,516

Water and Sewer

The usage is proportional to the tonnage milled, and has been found to cost $0.002 per ton. Rather than going through the tedious procedure used for estimating lighting and gas costs, the water and sewer costs are estimated by multiplying the annual tonnage by $0.002 per ton. This method is felt to be valid because the cost per ton was nearly constant throughout the periods tested, and because the volume consumed is low enough that the same utility rate applies.

TABLE A-18

Annual Water Costs for Combinations
Of Mills and Shifts
(Based on Cost of $0.002 Per Ton)

	Number of Mills			
	1	2	3	4
One Shift	$49	$ 98	$147	$196
Two Shifts	$98	$196	$294	$392

Tractor and Transfer Trailer Requirements

The number of trailers and tractors required is computed below. Based on actual data a 70-yard trailer loaded with 15 tons of milled refuse would have a density of 430 lbs. per cubic yard. Each trailer is limited to 15 tons because of State highway regulations. Past experience has shown that switching and unloading of each trailer averages 30 minutes when the plant is located on the fill site. At a mill production of 14 tons per hour one mill will fill one trailer in 64 minutes. Two mills operating at 14 tons per hour each will fill one trailer in 32 minutes. Thus a one mill plant will need a minimum of two trailers. A two mill plant could also function with only two trailers; but would be advised to have three to minimize production down time because of trailer breakdowns or delays in the switching-unloading process. Both a one mill and two mill plant would require only one tractor to pull the trailers. The above data would be applicable to a one shift or two shift operation.

As mentioned previously any three or four mill plant should contain two stationary compactors. Taking this and the above data into consideration, a three mill plant would require four trailers and a four mill plant five trailers. Each three and four mill plant should be equipped with a minimum of two tractors. Table A-19 summarizes the above data.

TABLE A-19

Tractor and Trailer Requirements

	Number of Mills			
	1	2	3	4
One Shift				
Tractors	1	1	2	3
Trailers	2	3	4	5
Two Shift				
Tractors	1	1	2	3
Trailers	2	3	4	5

Annual Tractor and Transfer Trailer Operation and Maintenance Costs

Maintenance on the tractors and trailers is charged on a mileage basis; $0.20/mi. for tractors and $0.25/mi. for trailers. To compute maintenance costs it is first necessary to determine the number of loads taken to the fill site; based on the information given above.

TABLE A-20

Number of Loads Per Day

	Number of Mills			
	1	2	3	4
One Shift	7	14	21	28
Two Shifts	14	28	42	56

The annual operating cost for the tractors can be computed as follows: multiply the number of daily trips by round trip distance traveled, 0.5 mile in Madison, x $0.20/mi. x 245 operating days/year. The computation for the trailers is the same except $0.25/mi. is used instead of $0.20/mi. The appropriate annual cost for tractor and trailer maintenance is shown in Table A-21.

TABLE A-21

Annual Operation and Maintenance Cost For Tractor and Transfer Trailer Operation Per Unit

	Number of Mills 1	2	3	4
One Shift				
Tractors	$172	$ 344	$ 516	$ 688
Trailers	215	430	645	860
Total	$387	$ 774	$1,161	$1,548
Two Shifts				
Tractors	$344	$ 688	$1,032	$1,376
Trailers	430	860	1,290	1,720
Total	$774	$1,548	$2,322	$3,096

Annual Stationary Compactor Maintenance Costs

Past studies conducted at the Madison plant have revealed that on the average, stationary compactor maintenance has cost approximately $0.02/ton, based on a one shift operation. It would be reasonable to assume that a 50 percent increase in costs would be experienced when the machinery is operated on a two shift basis. Using these figures as a guide the annual operating costs for the combination of shifts and mills being studied is shown in Table A-22. It should be reemphasized that all three and four mill plants are designed for two compactors.

TABLE A-22

Annual Stationary Compactor Maintenance Costs

	Number of Mills 1	2	3	4
One Shift				
First Compactor	$ 480	$ 960	$ 960	$ 960
Second Compactor	-	-	480	960
Total	$ 480	$ 960	$1,440	$1,920
Second Shift				
First Compactor	$1,440	$2,880	$2,880	$2,880
Second Compactor	-	-	1,440	2,880
Total	$1,440	$2,880	$4,320	$5,760

Annual Front End Loader Operation and Maintenance

For one and two mill operations a small end loader would be sufficient to handle all tonnage processed. For a three and four mill plant, a medium range end loader would be required. The operation and maintenance of both pieces of equipment is assumed to cost $4.25/hr. The end loader will operate 5 hours and 10 hours per day for a one mill, one shift and one mill, two shift operation, respectively. The same piece of machinery will operate 6 hours and 12 hours per day for a two mill, one shift and two mill, two shift operation, respectively. The end loader will operate 7 and 14 hours for a three mill, one and two shift operation, and 7 and 14 hours for a four mill, one and two shift operation, respectively.

TABLE A-23

Annual Operation and Maintenance Costs
For Front End Loader

	Number of Mills			
	1	2	3	4
One Shift	$ 5,205	$ 6,246	$ 7,287	$ 7,287
Two Shifts	$10,410	$12,492	$14,575	$14,575

Amortization*

Amortization data and annual costs are listed below for all depreciable items.

Building

Amortize over 20 years at 4.0 percent interest, salvage estimated at 3.0 percent of original cost as contained in Table A-5.

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*Amortization or annual cost is calculated on the basis of the following equation: [1]

A.C. = (P-L) (CRF) - Li

where
A.C. = annual cost
P = initial investment
L = salvage value
CRF = capital recovery factor
i% = interest rate
N - rated full life

The interest rate, i%, used in the computations, is a function of the expenditure involved; i.e., short term notes or long term bonds. The City of Madison usually funds large expenditures by long term bonds. The interest rates in effect at the time of writing are 4.0 percent on long term bonds.

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[1] Grant, Eugene L. and Ireson, W. Grant. Principles of Engineering Economy, Fourth Edition. New York: The Roland Press, 1964.

TABLE A-24

Annual Cost of Foundation and Building

	Number of Mills 1	2	3	4
One Shift	$12,720	$19,690	$32,250	$39,200
Two Shifts	$15,330	$26,130	$41,640	$43,980

TABLE A-25

Amortization* Data and Annual Costs

Cost Item	Original Cost	Depreciation Rate-Yrs.	Int. Rate, %	Salvage Value	Annual Cost
Scale	$15,000	20	4.0	$ 1,000	$ 1,076
Front Endloader					
Michigan	$32,000	12	4.0	$ 5,000	$ 3,089
Case	$22,000	12	4.0	$ 3,000	$ 2,153
Grinder and Conveyor (ea)	$140,000	15	4.0	$ 4,000	$12,400
Stationary Compactor (ea)	$ 22,000	15	4.0	$ 1,000	$ 1,930
Trailers (ea)	$ 19,000	12	4.0	$ 750	$ 1,982
Tractor (ea)	$ 15,000	15	4.0	$ 1,500	$ 1,275

Annual Projected Operating and Amortization Costs For Combinations of Mills and Shifts

Tables A-26 and A-27 summarize all costs of operating the various sized plants and the amortization rates of each.

*NOTE: This is not a surplus fund for replacement of equipment, but reflects municipal approaches for amortization.

TABLE A-26

Annual Cost for One Through Four Mills - One Shift

	Number of Mills			
	1	2	3	4
Labor	$ 70,430	$ 85,420	$108,150	$139,800
Mill Maintenance	8,580	18,720	28,100	37,500
Power - Mills, Conveyors, and Compactors	5,740	9,720	14,210	18,190
Lighting	1,060	2,020	3,420	4,180
Gas (Heat)	1,750	2,580	4,100	4,950
Water	50	100	150	200
Tractor and Trailer Operations and Maintenance	390	770	1,160	1,550
Front End Loader Operation and Maintenance	5,210	6,250	7,290	7,290
Compactor Maintenance	480	960	1,440	1,920
Subtotal, Operating Costs	$ 93,690	$126,540	$167,920	$215,580
Amortization				
Building	$ 12,720	$ 19,690	$ 32,250	$ 39,200
Scale	1,080	1,080	1,080	1,080
Front End Loader	2,150	2,150	4,090	3,090
Mill(s) and Conveyors	12,400	24,800	37,200	49,600
Stationary Compactor(s)	1,930	1,930	3,860	3,860
Trailers	3,960	5,940	7,960	9,940
Tractor(s)	1,280	1,280	2,560	3,840
Subtotal, Amortization	$ 35,520	$ 56,870	$ 88,000	$110,610
Total Annual Cost	$129,210	$183,410	$255,920	$326,190

TABLE A-27

Annual Costs for One Through Four Mills - Two Shifts

	Number of Mills			
	1	2	3	4
Labor	$102,080	$126,910	$164,630	$197,950
Mill Maintenance	18,160	35,150	53,040	70,850
Power - Mills, Conveyors, and Compactors	8,060	14,110	20,930	26,980
Lighting	2,000	3,460	5,610	6,910
Gas (Heat)	2,980	4,900	7,720	9,520
Water	100	200	290	390
Tractor and Trailer Operation and Maintenance	780	1,550	2,320	3,100
Front End Loader Operation and Maintenance	10,410	12,490	14,580	14,580
Compactor Maintenance	1,440	2,880	4,320	5,760
Subtotal Operating Costs	$146,010	$201,650	$273,440	$336,040
Amortization				
Building	$ 15,330	$ 26,130	$ 41,640	$ 43,980
Scale	1,080	1,080	1,080	1,080
Front End Loader	2,150	2,150	3,090	3,090
Mill(s) and Conveyors	12,400	24,800	37,200	49,600
Compactor(s)	1,930	1,930	3,860	3,860
Trailers	3,960	5,940	7,960	9,940
Tractor(s)	1,280	1,280	2,560	3,840
Subtotal Amortization	$ 38,130	$ 63,310	$ 97,390	$115,390
Total Annual Cost	$184,140	$264,960	$370,830	$451,430

Landfilling Cost Projections

Landfill cost projections will be based on the tonnages processed by each combination of mills and shifts discussed in the previous section. Costs will include labor for compaction, machine operation and maintenance, and equipment amortization. Land costs are excluded. No charges are projected for cover material since no daily cover is used when landfilling milled refuse at Madison.

Labor and Equipment Requirements and Costs:

Projections based on data obtained at Madison reveal that one operator utilizing a steel wheeled compactor can efficiently handle 300 to 360 tons of milled refuse per day. Based on this projection and the assumption that landfills adjacent to the projected plant operations will be operated only one 8-hour shift per day, the following labor and equipment requirements are made.

TABLE A-28

Daily Landfill Labor and
Equipment Requirements

	Number of Mills			
	1	2	3	4
One Shift				
Tons per day	100	200	300	400
Man Shifts	1	1	1	1
Trash Pak(s)	1	1	1	1
Two Shifts				
Tons per day	200	400	600	800
Man Shifts	1	1	2	2
Trash Pak(s)	1	1	2	2

TABLE A-29

Annual Labor Costs - Landfill Operations

			Number of Mills			
	Employee	Annual* Wage	1	2	3	4
One Shift	Operator	$13,000	$13,000	$13,000	$13,000	$13,000
	Site Control	11,300	5,650	5,650	11,300	11,300
	Supervisor	15,100	3,800	3,800	7,500	7,500
	TOTAL		$22,450	$22,450	$31,800	$31,800
Two Shift	Operator	$13,000	$13,000	$13,000	$26,000	$26,000
	Site Control	11,300	5,650	11,300	11,300	11;300
	Supervisor	15,100	3,800	7,500	15,100	15,100
	TOTAL		$22,450	$31,800	$52,400	$52,400

*Includes 30% fringe benefits excluding overtime.

To compute equipment operating and maintenance costs it is assumed that the landfill compactor will operate a minimum of 2 hours per 8 hour day and a maximum of 6 hours per 8 hour day at the rate of spreading and compacting 45 to 65 tons of milled refuse per hour. Operation and maintenance for landfill equipment are charged at the rate of $6.25/hour of operation. Compactor amortization is charged at the rate of $5,960 per year for an initial investment of $45,000 and an 8-year equipment life.

TABLE A-30

Annual Operating and Maintenance Costs - Landfill Equipment

	Number of Mills			
One Shift	1	2	3	4
Hours	990	1,225	1,470	1,715
Compactor Cost	$6,130	$ 7,660	$ 9,190	$10,720
Misc. Equipment Cost	610	770	920	1,070
Total Cost	$6,740	$ 8,430	$10,110	$11,790
Two Shifts				
Hours	1,225	1,715	2,940	3,430
Compactor Cost	$7,660	$10,720	$18,380	$21,440
Misc. Equipment Cost	770	1,070	1,840	2,140
Total Cost	$8,430	$11,790	$20,220	$23,580

Total Annual Projected Landfilling Costs:

TABLE A-31

Annual Projected Landfilling Costs

Landfill	Number of Mills 1	2	3	4
One Shift				
Labor	$22,450	$22,450	$31,800	$31,800
Compaction Equipment - Operation and Maintenance	6,740	8,430	10,110	11,790
Subtotal Operating Costs	$29,190	$30,880	$41,910	$43,590
Depreciation - Compaction Equipment	$ 5,960	$ 5,960	$11,920	$11,920
Total Operating Costs	$35,150	$36,840	$53,830	$55,510
Two Shifts				
Labor	$22,450	$31,800	$52,400	$52,400
Compaction Equipment - Operation and Maintenance	8,430	11,790	20,220	23,580
Subtotal Operating Costs	$30,880	$43,590	$72,620	$75,980
Depreciation - Compaction Equipment	5,960	5,960	11,920	11,920
Total Operating Costs	$36,840	$49,550	$84,540	$87,900

Summary of Annual Milling and Landfilling Costs

TABLE A-32

Annual Cost of Milling, Milled Refuse Transfer System and Landfilling - One Shift

	Number of Mills			
	1	2	3	4
Annual Tonnage	24,500	49,000	73,500	98,000
Reduction Plant & Transfer				
Operating Costs	$ 93,690	$126,540	$167,920	$215,580
Amortization	35,520	56,870	88,000	110,610
Total Reduction Plant	$129,210	$183,410	$255,920	$326,190
Cost Per Ton*	$5.27	$3.74	$3.48	$3.33
Millfill				
Operation Costs	$ 29,190	$ 30,880	$ 41,910	$ 43,590
Amortization	5,960	5,960	11,920	11,920
Total Landfill	$ 35,150	$ 36,840	$ 53,830	$ 55,510
Cost Per Ton**	$1.43	$0.75	$0.73	$0.57
TOTAL ALL OPERATIONS	$164,360	$220,250	$309,750	$381,700
COST PER TON	$6.70	$4.49	$4.21	$3.90

*Cost includes amortization, labor, operating, and milled refuse haul to landfill less than one-half mile round-trip distance. Land cost excluded.

**Millfill cost includes labor and equipment costs with amortization. Land cost and site preparation costs are excluded.

TABLE A-33

Annual Cost of Milling, Milled Refuse Transfer System and Landfilling - Two Shifts

	Number of Mills			
	1	2	3	4
Annual Tonnage	49,000	98,000	147,000	196,000
Reduction Plant & Transfer				
Operating Costs	$146,010	$201,650	$273,440	$336,040
Amortization	38,130	63,310	97,390	115,390
Total Reduction Plant	$184,140	$264,960	$370,830	$451,430
Cost Per Ton*	$3.75	$2.70	$2.52	$2.30
Millfill				
Operating Costs	$ 30,880	$ 43,640	$ 72,620	$ 75,980
Amortization	5,960	5,960	11,920	11,920
Total Landfill	$ 36,840	$ 49,600	$ 84,540	$ 87,900
Cost Per Ton	$0.75	$0.50	$0.57	$0.45
TOTAL ALL OPERATIONS	$220,980	$314,560	$455,370	$539,330
COST PER TON**	$4.50	$3.20	$3.09	$2.75

*Cost includes amortization, labor, operating, and milled refuse haul to landfill less than one-half mile round-trip distance. Land cost excluded.

**Millfill cost includes labor and equipment costs with amortization. Land cost and site preparation costs are excluded.

APPENDIX B
POSITION ON LANDFILLING OF MILLED SOLID WASTE *

A. BACKGROUND

The landfilling of milled solid waste without daily soil cover began in Europe with claims that it was an environmentally acceptable and economic method of final disposal. In June of 1966, a solid waste demonstration grant was awarded to Madison, Wisconsin to evaluate the European experience and to determine the feasibility of landfilling milled solid waste without daily cover in this country.

In January 1971, the Madison project personnel met with OSWMP personnel, a consulting engineer, and entomologists from the Bureau of Community Environmental Management (USDHEW), to review the progress and findings to date from the Madison project. OSWMP concluded that the policy governing soil cover for milled solid wastes should be as stated in Sanitary Landfill Facts:

> "The compacted solid wastes must be covered at the conclusion of each day, or more frequently if necessary, with a minimum of six inches of compacted earth."

It was also concluded that further investigation at Madison and in other geographic and climatic areas was needed to fully resolve the policy issue. In a February 2, 1971 memorandum, Mr. Richard Vaughan expressed these findings to OSWMP Senior Staff and Regional Representatives.

Additionally, environmental evaluations of landfilling milled solid waste made at the Madison demonstration site have been augumented by information from site visits to other facilities. An increased interest in the procedure is evidenced by the knowledge of six new sites being planned, ten new sites under construction, and five sites operational.

Some of these sites are constructed and operated with provisional approvals, some are operated in opposition to local regulations but in all cases the operations do not adhere to the position stated by the OSWMP on February 2, 1971.

Recent articles, based on European experience, findings from the Madison project, and other new sites within the United States, have appeared in engineering and public work journals. This information, combined with equipment promotional activities has generated an increased interest in the process particularly where problems exist in achieving satisfactory sanitary landfill operations or where milling may compliment resource recovery.

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*This appendix, not a part of the grantee's original report, was prepared and added by the Office of Solid Waste Management Programs, U.S. Environmental Protection Agency.

B. CURRENT POSITION

Landfilling milled solid wastes can be an environmentally acceptable method of final disposal. The same sound engineering principles involved in sanitary landfill sites, including a properly located, designed, financed, and operated milling facility must be provided to insure successful operations and to minimize adverse environmental impacts. Since environmental, economical, and operational conditions vary from existing sites, the need for cautious planning to meet local conditions and to determine the feasibility of each new site must be emphasized.

It must be recognized that this position is based on detailed investigations at the Madison site augumented by general knowledge from a few additional sites. The ability to mill, grind, or shred wastes such that it is environmentally acceptable to landfill them without daily cover is dependent on the process, its operation, and local conditions such as the environment and the waste content. It is, therefore, recommended that conditional approvals be given by regulatory agencies contingent upon verification that the quality of operation necessary to minimize environmental hazards is maintained. Such verification should be supported by operational controls and monitoring.

Except as modified below, the position statement on sanitary landfill applies to milled solid waste disposal operation. Comments relating milled solid waste to sanitary landfill requirements are listed below in the order presented in the pending "Guidelines for the Land Disposal of Solid Wastes."

1. As an alternative to sanitary landfill, landfilling milled solid waste without daily soil cover can result in increased surface water infiltration and accelerated decomposition which in turn can result in earlier leachate production and temporarily increased pollutional concentrations. Under the usual situation of landfill construction over a period of years, peak leachate production and concentrations occur only in a small part of the fill at any one time. In areas where rainfall infiltration exceeds evaportranspiration and field capacity is reached, the total production of leachate constituents has been shown to be equivalent to a sanitary landfill which reaches field capacity and produces leachate. Therefore, in accordance with the sanitary landfill position, it is necessary to prevent leachate from entering surface or underground sources of water supply. This can be accomplished by preventing leachate production and/or by collecting and treating leachate should it occur.

2. As with sanitary landfill operations, design and operation must conform to applicable air quality standards; specifically, open burning of solid waste must be prohibited.

3. As with sanitary landfill cover, compacted, milled, uncovered landfill surfaces must be left undisturbed to prevent odor. This does not preclude vehicular traffic but precludes excavation of a finished surface.

4. Although milling solid waste reduces the tendency for paper to blow during placement, satisfactory control requires that the waste be spread to a smooth contour and compacted promptly after placement.

5. A milled, uncovered solid waste landfill is much less obnoxious than an open dump and to many observers is no more obnoxious than bare earth.

6. Free venting or loss of gases from milled solid waste, experienced in test cells, indicates that milled solid waste without cover is less likely to trap gases in pockets or cause horizontal gas migration. However, the addition of cover or possible migration through fissures or broken pipe lines, etc. requires the same attention to gas control as a sanitary landfill.

7. European experience, verified by tests at Madison, Wisconsin and Purdue University indicates that:

> Rats cannot extract sufficient food to sustain life from properly milled combined residential, commercial solid waste (7-1/2 % organics wet weight in test) nor are they attracted more readily to an uncovered milled solid waste landfill than to a sanitary landfill (baiting studies); the milling process kills nearly 100% of the maggots present in incoming solid waste virtually eliminating fly emergence (sampling studies); and flies are not attracted more readily to an uncovered milled solid waste landfill (Scudder Grill Study).

8. Undetected hazardous materials in incoming wastes have been known to explode or ignite during the milling process. Protection against explosions such as blow-off stacks and personnel shields must be provided. Equipment to extinguish fires which may exist in incoming solid waste or which may be ignited during the milling process, during transport or on the landfill must be provided. No operation should be located where birds might be a hazard to aircraft flight operations.

9. Site selection on an engineering basis is similar to that for a sanitary landfill operation except the availability of daily cover material is not required. The availability of emergency cover is required (see operational plan requirements below). Final cover and final use criteria should be the same as for a standard sanitary landfill.

10. Only properly milled residential and commercial solid wastes should be accepted in an uncovered milled solid waste landfill. Items not accepted in a conventional sanitary landfill and volatile, flammable, explosive or sludge wastes accepted in small quantities at a conventional sanitary landfill, should not be accepted for milling. Final disposal of all wastes not suitable for milling must be in accordance with pending "Guidelines for the Land Disposal of Solid Wastes."

11. All operations and aspects including lighting, dust control, and noise levels must meet the requirements of the Occupational Safety and Health Act of 1970. All solid waste storage areas must be maintained and cleaned at the end of each day's operations, or during continuous operation, as necessary, to prevent fly, rodent, or other vector problems. All equipment must be maintained to control spillage and to achieve a milled product quality necessary to prevent environmental hazard.

12. All operational personnel must be specially trained and instructed on the proper operation, maintenance, and safety aspects of the facilities and equipment.

13. The operational plan must include provision for removal and proper disposal of wastes within 24 hours should the mill facility cease to meet the above conditions because of either a temporary equipment breakdown or a loss of quality operation. The operational plan must include provision of a stock pile of emergency soil cover material and provision to convert the operation to a sanitary landfill.

Preliminary project planning must include a detailed cost analysis including means of establishing a sound financing and revenue system, in order to guarantee that the quality of operation necessary for environmental acceptability can be sustained. Milling and landfilling residential and commercial solid wastes is usually not cost competitive with conventional sanitary landfill disposal. Cost comparisons to justify milling as an alternative to more extensive disposal systems including transfer stations or cover material transport must be evaluated on a local basis. Each community or private operator must make their own thorough economic evaluation of the alternative disposal systems. Milling costs including labor, amortization, utilities, maintenance, and supplies recorded at and relevant only to the Madison project were as high as $7.07/ton for a single 9 ton/hr. Gondard mill operating 5 to 6 hours a day. Costs for a single 15 ton/hr. Tollemache mill operating about 5 hours a day have been recorded at $5.10/ton while costs for a similar operation with "hard to mill" wastes ran as high as $6.44/ton. Transportation to the adjacent landfill averaged about $0.40/ton additional. Spreading and compacting costs averaged an additional $0.50 ton. Cost projections for the combined operation of one Gondard mill at 9 ton/hr. and one Tollemache mill at 15 ton/hr., milling 280 tons/day or a two shift operation is approximately $3.50/ton excluding transport and disposal. These costs reflect local labor rates, union contracts, construction costs, and electrical costs, etc.

C. REFERENCES

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